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Review p. 80
Make Football Safer

Feature p. 30
A Cure for Down Syndrome?

Business Report p. 61
Funding Innovation

(DON'T)

PANIC

WHAT TO DO ABOUT CLIMATE CHANGE.
p. 38

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From the Editor

I don't recall when I first heard about climate change. It was before Jim Hansen, then director of NASA's Institute for Space Studies in Manhattan, testified before the U.S. Congress on June 23, 1988. Then, he told the Senate Energy and Natural Resources Committee, "It is time to stop waffling so much and say that the evidence is pretty strong that the greenhouse effect is here."

I am 48 years old; I have been hearing about climate change most of my life. We have been waffling the whole time. Yet until recently there was some sense, however inchoate, that significant changes were still avoidable if we acted. It's now clear to everyone except the most inveterate climate-change skeptics that what Hansen told Congress in 1988 is the case: climate change is here. As Ken Caldeira, a climate scientist at the Carnegie Institution for Science, writes in "Stop Emissions!" on page 40, part of this issue's coverage of climate change: "Already, in the middle latitudes of the Northern Hemisphere, average temperatures are increasing at a rate that is equivalent to moving south about 10 meters (30 feet) each day." We failed to act in time.

What's left to be discovered is how bad it will be, how fast it will happen, and what we will do about it. The first great unknown is how quickly we will abandon coal, petroleum, and natural gas. If we burn all available fossil-fuel resources and dump the resulting carbon dioxide into the air, global average temperatures could rise as much as 9 °C; mammals might not be able to live at the waist of the Earth. That probably won't happen, but to limit temperature increases, we must swiftly deploy the low-carbon energy technologies that we do understand, such as solar and wind power, while researching and developing solutions to energy problems that still elude us, like how to store the electricity generated by renewable sources or generate power from safer, cheaper nuclear reactors. These efforts will require smart energy policies, international treaties, and a significant increase in the amount nations spend on energy R&D.

Other unknowns are the climate's sensitivity to increases in atmospheric carbon dioxide and the impact those temperature increases will have. David Rotman, *MIT Technology Review*'s editor, argues (see "Hot and Violent," page 70), "No one knows how climate change will transform our lives. Not only is it uncertain how much elevated levels of carbon dioxide in the atmosphere will raise temperatures and affect precipitation in different parts of the world, but there remains much to learn about how these changes will reduce agricultural productivity, damage human health, and affect economic growth." Could climate change, Rotman asks, "lead to a far more violent world?"

At least 2 °C of global warming, which was once thought the upper band of what we could bear as a civilization, now seems locked in. More may be likely. We must begin to imagine the social, economic, agricultural, and engineering implications of living in that future, and plan accordingly. It will be hotter; seas will rise and flood cities; there will be more droughts and storms, and crops will fail; the nations will fight; and refugees will stream from the poor parts of the world.

Faced with all this, it's easy to recall the words of Job 3:25—"The thing which I greatly feared is come upon me, and that which I was afraid of is come unto me." But it's never too late until it's too late; life goes on unless it doesn't. We have to decide what we want to do next. That's the moral imperative and the practical reality. Don't panic.

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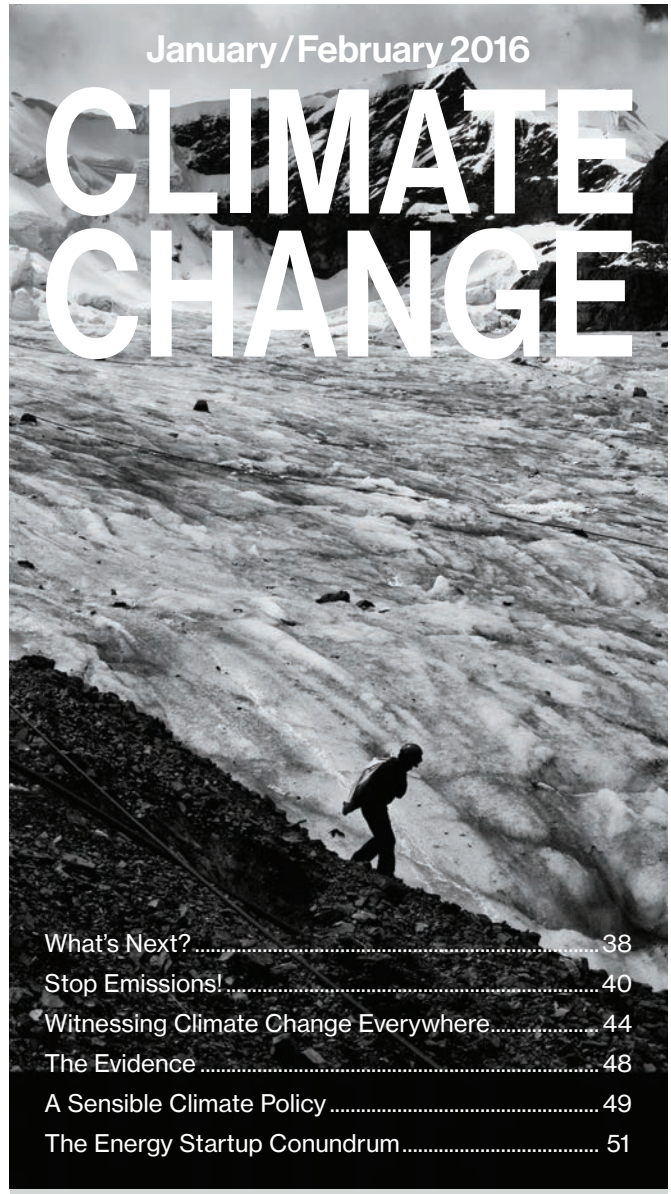
Contents

Front



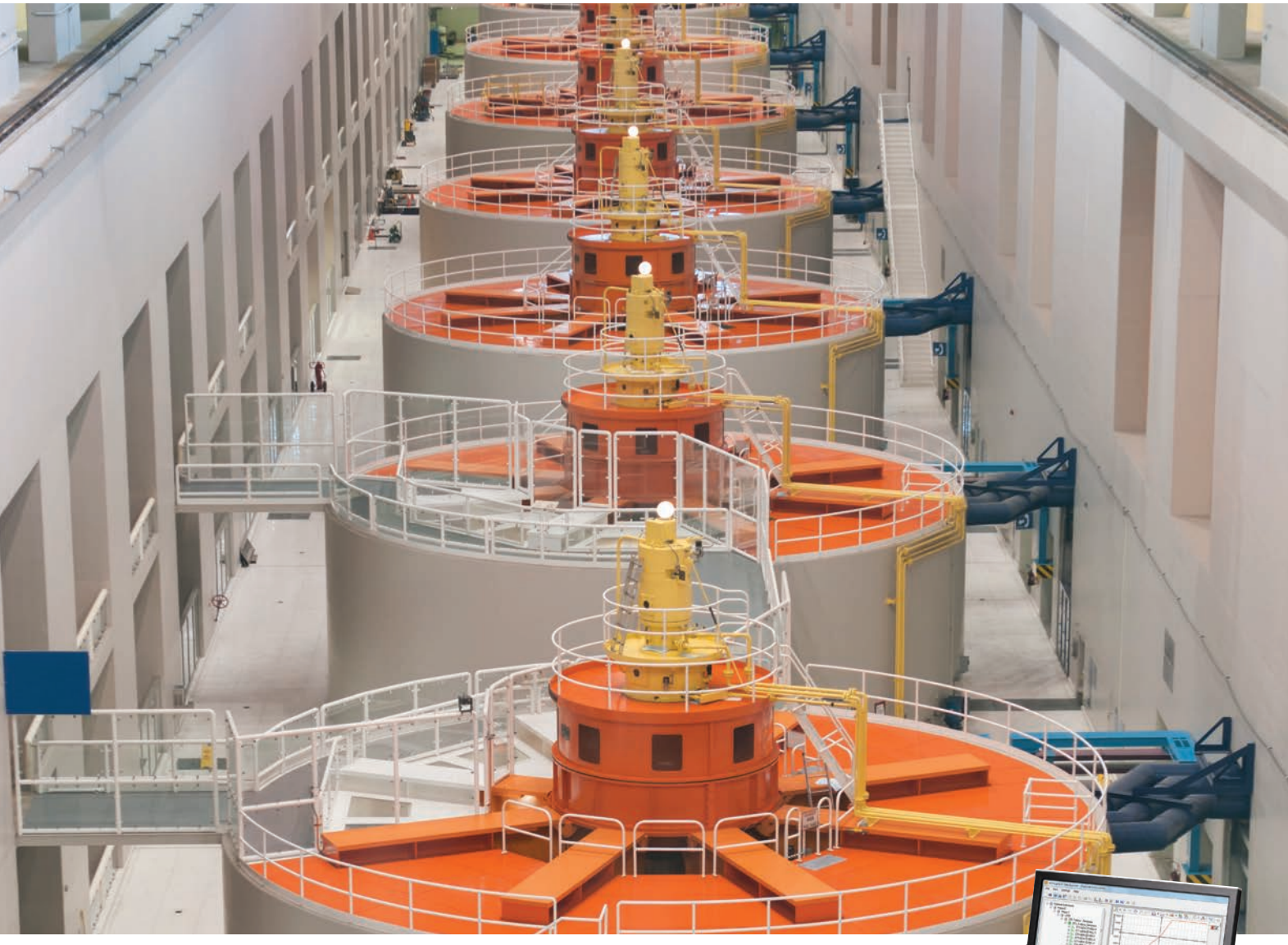
Back

ON THE COVER

Design by Neil Donnelly

PHOTOGRAPH BY MICHAEL ROBINSON CHÁVEZ

Who will prevent downtime and equipment failure?



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BIOMEDICINE

With This Genetic-Engineering Technology, There's No Turning Back

Designers of a "selfish" gene able to spread among mosquitoes say it could wipe out malaria, but the scientific community is at odds over whether or not we should use it.

ENERGY **New Material Makes It Easier to Store Lots of Natural Gas**	COMPUTING **Claimed Breakthrough Slays Classic Computing Problem**
ROBOTICS **How Robots Can Quickly Teach Each Other to Grasp New Objects**	MOBILE **Track Your Heart with Your Phone, Even If Your Phone's in Your Bag**
BIOMEDICINE **Patients Favor Changing the Genes of the Next Generation with CRISPR**	COMPUTING **The Ad-Blocking Kingpin Reshaping the Web as He Prefers It**

FROM THE ARCHIVES

Virtual Reality Check

October 1993

Even in its nascency, virtual reality showed much of the promise we're realizing today.

TECHNOLOGYREVIEW.COM/1993VIRTUAL

World Changing Ideas

April 2005

A look at technological projects and problems from seven countries around the globe.

TECHNOLOGYREVIEW.COM/2005WORLD

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REPUBLIC OF TURKEY PRIME MINISTRY
INVESTMENT SUPPORT AND
PROMOTION AGENCY

Introducing Turkey's Next-Generation Mobile Network

In August 2015, Turkey took a major step toward a new era of wireless communication, when the government distributed frequency rights for a 4.5G network among the country's three mobile operators as part of a USD $3.9 billion government tender.

Turkish officials expect the next-generation network to generate USD $17 billion for Turkey's economy in the next few years.

The new LTE Advanced network, scheduled to launch by April 1, 2016, will provide Turkey's current 61 million 3G mobile subscribers with a speedier, smoother, more secure way to access the Internet, make calls, watch streaming video, listen to music, and more. Officials expect the country's mobile users, especially its dynamic, tech-savvy young people, to embrace the improved network.

The new network will also be essential for achieving the goals of Vision 2023, the ambitious set of economic and technology initiatives that Turkey has targeted for the centennial of its founding.

Boasting speeds up to 14 times faster than the 3G networks, the new 4.5G network represents a significant upgrade to Turkey's telecommunications infrastructure. According to government specifications, the network will reach 95 percent of Turkey's 77 million residents, bringing the latest in wireless communications to the country's remotest corners and further bolstering the republic's status among the world's most developed nations.

The effort to establish the Advanced LTE network in Turkey resulted from collaboration between the wireless operators and several technology and network companies. The infrastructure itself requires an investment of about USD $7.7 billion by the tender winners. Local development of network hardware and software, as specified by government requirements, will immensely benefit the country's information and communications technology (ICT) companies. It will also give Turkey's fast-growing ICT industry a competitive edge in the international arena as new markets adopt the next-generation wireless technologies.

Turkish officials expect the new 4.5G network to generate USD $17 billion for Turkey's economy in the next few years. The e-commerce sector in particular will benefit as the network strengthens mobile commerce and provides subscribers with faster and easier avenues for online shopping.

Early adopters, Internet businesses, technology companies, and the mobile-gaming industry all stand to gain competitive advantage from the new network. Public institutions such as ministries and municipalities, which serve millions of citizens every day, will also invest in new technologies so that they can offer better services.

The new network will also be essential for achieving the goals of Vision 2023, the ambitious set of economic and technology initiatives that Turkey has targeted for the centennial of its founding. In the years leading up to 2023, the topics of digital transformation and broadband policies and strategies will only grow in prominence as Turkey prepares economically, politically, and infrastructurally for its next century of existence.

Boasting speeds up to 14 times faster than the 3G networks, the new 4.5G network represents a significant upgrade to Turkey's telecommunications infrastructure.

For more information, visit: invest.gov.tr

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Five Most Popular Stories

MIT Technology Review
Volume 118, Number 6

1 India's Energy Crisis

India has a huge population, development needs that are staggering (India's population is poised to exceed China's in the 2020s), and an urgent need for energy to ensure decent standards of living for its people. The West powered the world's industries for the better part of the last two centuries; it would be hypocritical of them to ask India to pay a higher price. That's akin to a polite way of saying, "Be poor, consume less."

—**SanH2O**

2 Lyft's Search for a New Mode of Transport

Uber and Lyft are cheaper than taxis because they're being massively subsidized by early-stage investors. The article notes that informal "sharing" models can be found in less developed economies but fails to explain why a model that has never proved successful elsewhere should be seen as the basis for multibillion-dollar businesses today.

—**hubert_horan**

How "green" is it to have hundreds of drivers (who would not otherwise be on the road) circling around waiting on a ride?

—**biscuitsla**

3 A Shocking Way to Fix the Brain

Fascinating! I wonder if this procedure could be used to alleviate attention deficit disorders with hyperactivity. —**UconnRon**

The technology of deep brain stimulation holds out a wonderful brass ring when it succeeds, but too often patients are subject to raw experimentation with no recourse for the harms they experience. It's disturbing to contemplate how many suffering individuals will be tossed aside on the road to a successful treatment and billions in profits for the medical-device companies. —**Dead_live**

4 Fighting ISIS Online

Fifteen years ago, I thought networking technology would offer a great opportunity for people to form their own chosen networks, belong to more than one network, and socialize and enjoy their own groups. I thought this would provide an infinite number of virtual spaces and thus allow us to avoid battles for physical space. Instead, these gifts from technology have been used to intensify the wars for land rather than eliminate them.

—**Uttarabhadra**

5 The Hit Charade

It seems the author is setting a rather high bar for the algorithms. He writes that algorithms can't "distinguish between a truly original piece and yet another me-too imitation of a popular sound." Neither can many humans.

—**bowlweevils**

Whether a playlist is poignant or compelling is obviously subjective, but I've experienced juxtapositions on Pandora lists that I would describe in those terms. If you were to be given, say, 500 playlists, some created by humans and others by algorithm, I would be very surprised if you could identify at a high rate of accuracy which was which. —**cmfarrell57**

The Myth of India and Coal

"India's Energy Crisis," by Richard Martin (November/December 2015), is near comprehensive in its coverage of India's dilemma, but it falls back upon a set of myths—intuitively reasonable, ultimately wrong—that perpetuate the assumption that coal is India's top priority.

The first big myth is that coal will end India's "energy poverty." But not all energy poverty is electric. Over three times as many Indians lack clean and modern cooking as lack electricity. Electric stoves remain expensive and watt-hungry, so tackling three-quarters of India's energy poverty requires better markets and public programs for cleaner gas and biomass cookstoves. This has little to do with electricity supply—from coal or anything else.

Another myth is that coal will bring India cheap, reliable power. But coal won't solve grid reliability problems. India's notorious blackouts are as often imposed by distribution companies to manage demand from nonpaying consumers as they are caused by supply shortages.

India's blackouts are as often imposed by distribution companies as they are caused by supply shortages.

Coal also faces stiff price competition from wind and solar. Martin cites Skypower's winning bid in Madhya Pradesh; SunEdison also just won a solar auction in Andhra Pradesh. He dismisses these open bids as "unrealistically low prices," but he ignores the fact that the bids are backed by global companies entering long-term binding contracts. He also misses the broader economic benefits: renewables insulate distribution companies from fuel-price volatility, they don't burden trade balances, and they reduce inflationary pressures.

The myths found in Martin's article make clear that the conversation around coal power in India hasn't yet made sense of the available data.

Ilmi Granoff is an attorney in environmental law and policy, and a senior research fellow at the Overseas Development Institute.

Views

Barbara Strupp

Alison Gopnik

Nathan Freitas

BIOMEDICINE

Early Intervention

We need therapies to help those with Down syndrome reach their potential.

We currently have no therapeutic interventions that can prevent or reverse the intellectual disability or brain pathology found in individuals with Down syndrome, which affects about 400,000 people in the United States alone. However, we may be getting closer. Some researchers are working to develop drugs that could be used to treat Down syndrome in utero (see "A Change of Mind," page 30). For the last decade, my colleagues and I have been on a similar path.

Ten years ago, we were attempting to identify a pharmacological intervention that might improve cognitive functioning in mice with a condition mimicking Down syndrome. One colleague suggested that we look at increasing the mother's intake of the essential nutrient choline during pregnancy and lactation, on the basis of impressive cognitive benefits seen with this intervention in normal rats during research done at Duke. I was skeptical, but it was worth a try. A nutritional intervention was also appealing because it could be relatively easily tested in humans if our studies looked promising.

We found that supplementing the maternal diet with extra choline during pregnancy and lactation markedly improved spatial cognition, attentional function, and emotional reactivity in the mouse offspring with a model of Down syndrome. It also normalized the formation of new neurons in the hippocampus and protected basal forebrain cholinergic neurons, which normally atrophy in this disorder by midlife—part of the brain changes related to the onset of Alzheimer's.

How to explain these results? We suspect the answer might be found in studies done over the past few decades, showing that choline stores become depleted during pregnancy in both rodents and humans. A developing fetus may need more choline than previously realized.

Although clinical trials are needed to determine whether similar effects are seen in humans, anecdotal reports of women increasing their choline intake during a Down syndrome pregnancy are encouraging. The reports suggest that these infants reach milestones on a schedule more similar to that of typically developing babies than infants with Down syndrome whose mothers did not take extra choline. There's growing evidence to support a recommendation for all women to increase choline intake during pregnancy and breastfeeding—a change that could benefit all fetuses with Down syndrome from the earliest stages of development, regardless of whether the mom had prenatal testing.

Today, women who learn that they are carrying a fetus with Down syndrome are often advised to terminate the pregnancy. But for a variety of reasons, ethical and otherwise, that's not an option for all women. Some 5,000 infants with Down syndrome are born in the U.S. every year. It's imperative that we find a way to help them achieve their highest potential.

Barbara Strupp is a professor in the division of nutritional sciences and department of psychology at Cornell University.

COMPUTING

Child's Play

Computers should stop trying to act like grown-ups.

Everyone knows the Turing test. But almost no one remembers Alan Turing's statement that to achieve true intelligence, you should design a machine that

ANDY FRIEDMAN

was like a child. He said the real secret to human intelligence is our ability to learn.

Thirty years of developmental cognitive science have shown that children are the best learners on earth. But how do they learn so much so quickly? For the last 15 years developmental cognitive scientists and computer scientists have been trying to answer this question, and the answers shape new kinds of machine learning (see "Kindergarten for Computers," page 52).

Many of the recent advances in AI have come through techniques like deep learning, which can detect complicated statistical regularities in enormous data sets. Computers can suddenly do things that were impossible before, like labeling images on the Internet.

The trouble with this sort of purely statistical machine learning, though, is that it depends on data that's already been selected by humans. Machines need gigantic human-generated data sets just to be able to look at a new picture and say "kitty-cat!"—something a baby can do after seeing just a few examples.

An alternative in machine learning and cognitive science—the "probabilistic models" framework—takes a different approach. These systems formulate and test abstract hypotheses. Bayesian inference procedures have been particularly important. For example, you can mathematically describe a particular causal hypothesis as a directed graph that systematically generates a particular data pattern, and then calculate just how likely that hypothesis is to be true, given the data you see. Machines have become great at testing hypotheses against the data in this way, with consequences for everything from medical diagnosis to meteorology. We've shown that young children use data to evaluate hypotheses in a similar way.

But there are two things even very young children do that are still far beyond the abilities of current computers. We are trying to understand these abilities both formally and empirically, and these investigations may allow us to design more powerful kinds of AI.

The really hard problem is deciding which hypotheses, out of all the infinite possibilities, are worth testing. Even preschoolers are remarkably good at coming up with brand new concepts and hypotheses in a creative and imaginative way. In fact, our research has shown that they can sometimes do this better than grown-ups.

A second area where children outshine computers is in their ability to go out and explore and experiment with the world around them—we call this "getting into everything." Developmental cognitive scientists are just beginning to understand and formalize this kind of active learning. The wildly creative imaginations and ceaseless exploration of young children may be the key to their impressive learning abilities. Studying those children can give us clues about how to design computers that can pass the more profound Turing test and be almost as smart as a three-year-old.

Alison Gopnik is a professor of psychology at the University of California, Berkeley.

MOBILE SECURITY

The Encryption Myth

Law enforcement has plenty of tools to get your data, even with encryption.

"The terrorists are going dark"—that phrase came back into vogue after the Paris attacks of mid-November, implying that encryption is enabling attackers to go undetected. But we're being given a false choice: either we allow law enforcement unfettered access to digital communications or we let the terrorists win. It's not that simple.

It's true that much of the world's communication has shifted from easy-to-intercept text messages and phone calls to mobile apps that provide improved privacy and security. But there's still plenty of data that is not fully encrypted or not encrypted at all—the kind of data that officials say they need to catch the bad guys. Not all the approaches to getting the data are clearly legal, and many app developers (including me) are actively working to defend against them, since they're often used to monitor activists or journalists. But it's disingenuous to pretend they don't exist. Here are a few:

- If someone carries a mobile phone, his or her every movement, call, and use of the Internet is being tracked by the mobile service provider. Accessing this data often doesn't require a warrant.

- Even in well-regarded implementations by WhatsApp and Apple, it's probably possible to disable access to or reduce the strength of encryption on a per-user basis, without the user even knowing.

- An encrypted chat can be monitored if the app supports group chat or synching conversations among multiple devices. If law enforcement can compel the app service provider to add a new device to an account without notifying existing users, then they're in.

- Most cloud data is encrypted to protect it from attackers, not from the service provider itself. Some services say they encrypt data in the cloud, but the user doesn't hold the key—the service does. Law enforcement can thus get access to a cloud backup of all the messages, contacts, calendars, photos, location data, and more that users often unwittingly store there.

Whether we're aware of it or not, we're all constantly generating and exposing our private data, and the opportunities for targeted surveillance are vast—within both clearly legal and legally gray areas.

Nathan Freitas leads the Guardian Project, which develops open-source mobile security software.

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Upfront

SOPHIA FOSTER-DIMINO

Google's Great Virtual-Reality Experiment

Smartphones have sidelined digital cameras and other special-purpose devices. Now Google thinks its inexpensive Cardboard virtual-reality viewer will help mobile phones shove high-end VR headsets like the Oculus Rift into the shadows, too.

The bright black sand at Diamond Beach, Iceland, is dotted with smooth gray pebbles and glassy chunks of ice. The crash of foamy waves fills my ears as I turn my head to look down the beach and see the dark strip of sand fade into white fog as if it went on forever. I don't feel the cold, because I'm not really there. I'm in a windowless room at Google's headquarters, holding a cardboard

Upfront

box against my face so that it positions a smartphone two inches from my eyes. Google Cardboard, as both the phone holder and the accompanying app are called, transforms the computer in your pocket into a virtual-reality headset. It's something of a gimmick. It's also a serious attempt to create a new mass communication and entertainment medium. "Virtual reality will have an important role to play in entertainment, communications, work, and learning," says Clay Bavor, who leads Google's virtual-reality project.

Mark Zuckerberg, CEO of Facebook, also thinks virtual reality will change the world. He has predicted that it is "the next major computing and communication platform," a very serious claim in Silicon Valley business-speak. But Facebook and Google are trying to make it come true in almost opposite ways. In 2013, Facebook spent $2 billion to acquire Oculus VR, a company developing a sophisticated virtual-reality headset called the Rift that is held to your face with a thick elasticated strap and attaches via a cable to a powerful PC. The Rift goes on sale in early 2016. The price is unknown, but a version that until recently was available to developers cost $350, and an Oculus-approved PC to power its forthcoming headset costs at least $950. Facebook has also collaborated with Samsung on a $99 headset called the Gear VR, which can use some Samsung smartphones as a screen. But Samsung is unlikely to make the Gear VR compatible with its competitors' devices, and Facebook's main project is the high-end Rift experience.

In contrast, Cardboard works with iPhones and almost any phone running Google's Android software. Google has released the design of the Cardboard phone holder for free, and other companies sell versions for $10, or more if you want one in plastic, metal, or wood. Google estimates that it and other companies have sold or given away more than two million Cardboard kits. It has also begun sending Cardboard kits to schools with a special version of the app.

Cardboard transforms the computer in your pocket into a VR headset.

The Rift offers a far better experience than Cardboard and has spurred tech and media companies to invest hundreds of millions in virtual-reality startups, content, and copycat headsets from companies such as Sony and phone manufacturer HTC. But the technological tide that made the Rift possible also works against it—in Cardboard's favor. Even as the smartphone industry slashed the costs of the displays and sensors needed to build a good virtual-reality headset, smartphones have made people less inclined to spend money on PCs or on single-purpose gadgets such as cameras or GPS devices—and perhaps virtual-reality technology. "There's a set of enthusiastic users, me being one of them, that'll be willing to charge and plug in and assemble these things, and we're going to have a great experience," says Google's Bavor. And indeed, many people on his team are working on applications for high-end VR technologies, he says. But for virtual reality to go anywhere—and to answer the question of what on earth it's good for—it has to spread beyond that small niche.

Google has several initiatives designed to help its lightweight take on virtual reality take off. It is working with phone makers to ensure that future smartphones support Cardboard better. It has invented a new kind of camera to produce virtual-reality movies, and it is developing YouTube into a platform to deliver them. If it works, Google's gimmick might neutralize virtual-reality headsets before they even get properly established.

Google's goggles are made from the eponymous cardboard, a few Velcro patches, and two plastic lenses. Simple instructions explain how to fold the device together, download an app, and put your phone inside to jump into virtual space. The app splits a phone's display in two,

TO MARKET

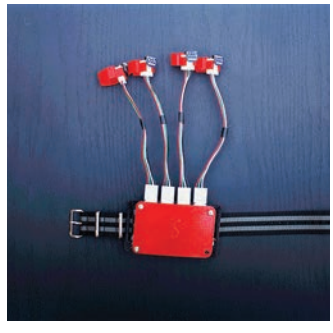
Gest

Hand motion sensor

COMPANY:
Gest

PRICE:
$200

AVAILABILITY:
Late 2016



Keyboards, mouses, and touch screens all have their uses, but all have distinct limitations. They're not particularly good for interacting with 3-D objects, such as those found in virtual-reality or design programs. A company called Gest thinks its device, which slides onto the back of your hands and fingers to track their movements, provides a more natural and useful alternative. The Gest controller has four soft, rubbery half-rings that clip onto your fingers, and a pad that straps onto the back of your hand. Each device contains 15 inexpensive sensors that measure motion with gyroscopes and accelerometers, much like those found in mobile phones. *—Signe Brewster*

COURTESY OF GEST

Cardboard is easy to fold and put to use with many kinds of smartphones.

COURTESY OF GOOGLE

and the goggles' lenses project a slightly different viewpoint to each of your eyes, so your brain perceives depth. To interact with what you see on the screen—to select from a virtual menu, say, or pause a movie—you press a button on top of the goggles. It swings a piece of metalized fabric against the phone's touch screen, which registers the tap of a fingertip.

Putting your expensive glass-and-metal pocket computer into a dowdy brown box you just folded together and raising it to your face feels a little silly. But watch someone try Cardboard for the first time, and you will usually see a grin beneath the plain brown goggles. "There is magic in the difference between your expectations and what it delivers," says Bavor. "You already have this device in your pocket that, when you add some cardboard, turns into a good VR viewer."

He is both right and wrong. It is somewhat surprising that your phone can function as a virtual-reality headset. But right now Cardboard is only okay, not good. For a few minutes it's great, but the discomfort and even nausea that VR can cause strike more readily than they do when you use a headset like the Rift. Current smartphone hardware can't update the virtual world in close enough synchrony with the movements of your head as you look around, which is what causes motion sickness. The Rift cuts that lag to less than 20 milliseconds, which can still leave some users nauseated. Cardboard's latency is significantly greater.

Google designed Cardboard without a head strap in recognition of that deficiency—and to make it more social. The idea is that your arms will get tired before you overexpose yourself or your friends get antsy for their turn. But one reason the Google VR team is now large enough to occupy its own building on the Google campus is that Bavor thinks smartphones offer a good enough experience for some purposes and will soon get much better. Google is talking with manufacturers about how their devices could help fix Cardboard's limitations—for example, by upgrading their motion sensors to be more accurate and to update their readings more frequently. Because its Android operating system powers 1.4 billion smartphones around the world, Google has significant influence on the companies that make them and how they perform.

When you ask virtual-reality developers what we will do with the technology and why, you often hear predictions about how we will physically engage with imaginary worlds and the objects and people in them. The Oculus Rift will ship with a game controller from Microsoft's Xbox, and Facebook will also sell complicated controllers that can be used to grab and manipulate virtual objects. Google is instead trying to make virtual reality into a new kind of casual, mostly passive entertainment like watching TV or surfing online videos—one perhaps more likely to win a mass audience and thus become a lucrative platform for ads or premium content.

Philip Rosedale, founder of the virtual world Second Life and CEO of High Fidelity, a startup developing ways to socialize in virtual spaces, thinks both Google's and Facebook's strategies will take longer to work out than the companies hope. "Next year there's going to be a big push to make VR a success, and it's not going to succeed," he says. He adds that mobile devices aren't capable of powering compelling virtual-reality experiences today.

Bavor acknowledges that Google and other companies investing in virtual reality have much to learn, but he says the only way to do it is to get the technology to a significant audience. And the device for doing that is already in our hands and in front of our eyes. "The technology's here," he says. "We've seen the proof that you can create wonderful VR experiences with today's smartphone hardware; the sensors and the hardware and the content are only going to get better." *—Tom Simonite*

Upfront

Gene-Edited Dogs

Genome engineering has created an extra-muscular beagle. Are we on our way to customizing the DNA of our pets?

Man's best friend is now his newest genetic-engineering project.

Scientists in China say they are the first to use gene editing to produce customized dogs. They created a beagle with double the usual amount of muscle mass by deleting a gene called myostatin. The dogs have more muscles and are expected to have stronger running ability, which is good for hunting, police, and military applications, Liangxue Lai, a researcher with the Key Laboratory of Regenerative Biology at the Guangzhou Institutes of Biomedicine and Health, said in an e-mail.

Lai and 28 colleagues reported their results in the *Journal of Molecular Cell Biology*, saying they intend to create dogs with other DNA mutations, including ones that mimic human diseases such as Parkinson's and muscular dystrophy. "The goal of the research is to explore an approach to the generation of new disease models for biomedical research," says Lai. "Dogs are very close to humans in terms of metabolic, physiological, and anatomical characteristics."

Lai said his group had no plans to breed the extra-muscular beagles as pets. Other teams, however, could move quickly to commercialize gene-altered dogs, potentially editing their DNA to change their size, enhance their intelligence, or correct genetic illnesses. A Chinese institute, BGI, said in September it had begun selling miniature pigs, created via gene editing, for $1,600 each as novelty pets.

Gene editing employs newly developed techniques that let scientists easily disable genes or rearrange their DNA letters. The method used to change the beagles, known as CRISPR-Cas9, is particularly inexpensive and precise. Lai's work is part of a large Chinese effort to modify animals using CRISPR. The list of animals already engineered using gene editing in China includes monkeys (see 10 Breakthrough Technologies, "Genome Editing," May/June 2014.)

Lai and his team introduced the gene-editing chemicals—a DNA-snipping enzyme, Cas9, and a guide molecule that zeroes in on a particular stretch of DNA—into 65 dog embryos. Their objective was to damage, or knock out, both copies of the myostatin gene so that the beagles' bodies would not produce any of the muscle-inhibiting protein that the gene manufactures.

In the end, 27 puppies were born, but only two, a female and a male, had disruptions in both copies of the myostatin gene. The researchers named the female beagle Tiangou, after the "heaven dog" in Chinese myth. They named the male Hercules.

Lai and his colleagues reported that in Hercules, the gene editing was incomplete, and a percentage of the dog's muscle cells were still producing myostatin. But in Tiangou, the disruption of myostatin was complete, and the beagle "displayed obvious muscular phenotype," or characteristics. For example, her thigh muscles were larger than those of her littermates.

The ease with which gene editing can be carried out has raised worries that humans could be next. Yet at least some researchers think gene-edited dogs could put a furry, friendly face on the technology. George Church, a professor at Harvard University who leads a large effort to employ CRISPR editing, said in an interview that he thinks it will be possible to improve dogs by using DNA edits to let them live longer or simply make them smarter.

Church said he also believed the alteration of dogs and other large animals could open a path to eventual gene editing of people. "Germ-line editing of pigs or dogs offers a line into it," he said. "People might say, 'Hey, it works.'"

—Antonio Regalado

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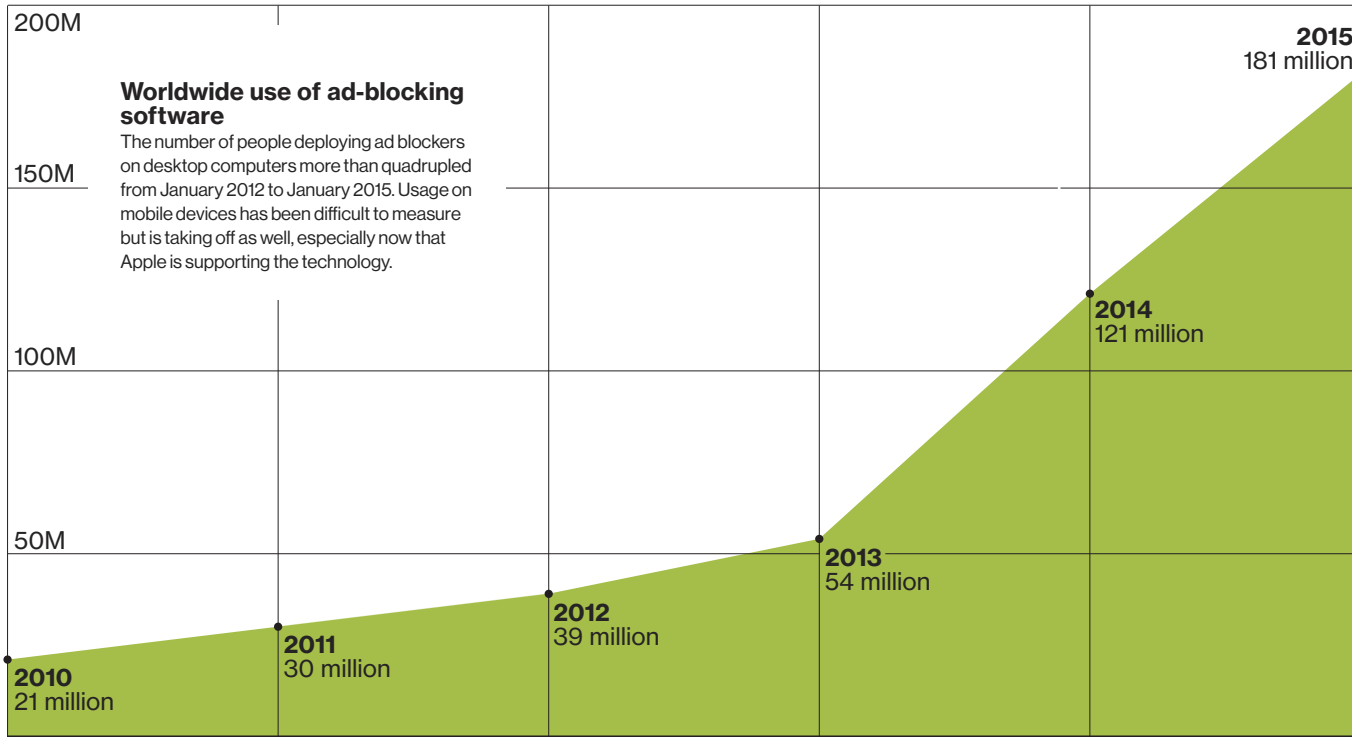
Upfront

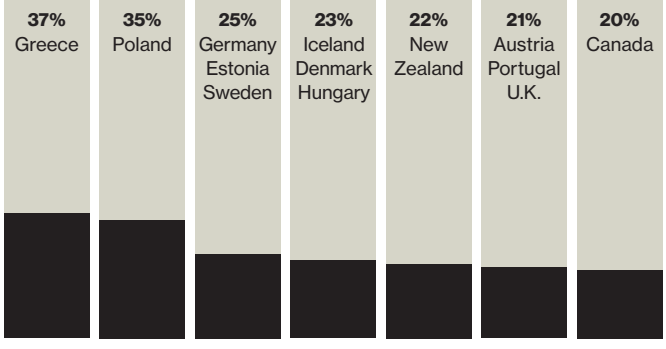
The Fast Rise of Ad Blockers

Software that prevents advertisements from loading on your computer or smartphone has gone mainstream so quickly that media companies are scrambling to figure out how to replace the revenue that makes countless free websites and apps possible (see "The End of Internet Advertising as We've Known It," page 76).



Top countries for ad blocking

More than one-third of desktop computer users in some markets are refusing to let ads load on their machines.



Spending on U.S. Internet ads, by type

One reason for the increasing popularity of ad blocking could be that advertisers are creating more video ads, which can make Web pages load slowly. Advertisers are also trying to get more ads onto the small displays of mobile devices.

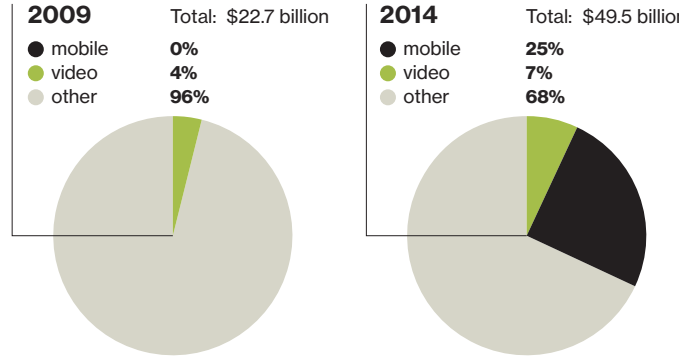


ILLUSTRATION BY LUKE SHUMAN; DATA FROM PAGEFAIR AND THE INTERACTIVE ADVERTISING BUREAU

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slack
Work on purpose

Upfront

QUOTED

"This is not good."

—Tesla Motors CEO Elon Musk, referring to evidence on YouTube that Tesla owners pushed a new autonomous driving feature too far. Tesla has since added constraints to prevent dangerous situations.

"Ads are horrible, but they are what we have."

— Wladimir Palant, who is trying to force companies to make better online ads with Adblock Plus, a popular app that blocks certain ads from Web pages.

"I don't know that we have to worry too much if we have a tech bubble burst."

— Nobel-winning economist Robert Shiller, who correctly predicted the first tech bubble and the housing bubble, acknowledging that there is a technology investing bubble today but its bursting shouldn't hurt as long as investors are diversified.

BY THE NUMBERS

2%

Proportion of people polled by Rock Health who would feel comfortable sharing their health data with Facebook.

5

Number of hours it takes a new device from T2 Biosystems to detect often deadly fungal sepsis, which otherwise takes at least a day to pinpoint.

2030

Year by which China expects to deploy advanced nuclear reactors commercially.

1

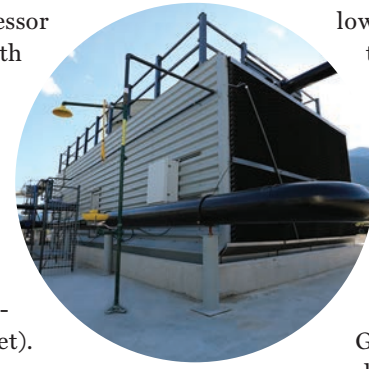
Number of hours it takes Tally, a retail inventory robot from Simbe Robotics, to scan shelves in a modest-sized CVS drugstore, compared with several days' worth of man-hours.

Taking Carbon from Air

Pilot plant in Canada tries to demonstrate carbon capture on an industrial scale.

Recently a group of government officials, environmentalists, and local bigwigs gathered in the coastal town of Squamish, British Columbia, about an hour north of Vancouver, to mark the start of what could one day be a new industry: turning carbon dioxide captured from air into carbon-neutral fuel for transportation.

The company that built the plant, Carbon Engineering, was founded by a Canadian scientist named David Keith. A Harvard professor of applied physics, Keith has made headlines before for his outspoken advocacy of more research into geoengineering (specifically, seeding the lower stratosphere with sulfuric acid to reflect sunlight and cool the planet). With the carbon-capture venture, though, Keith is being careful not to over-hype his company's technology: while Carbon Engineering's process should be able to strip carbon dioxide out of the air at a rate of around one ton per day, Keith emphasizes that it's not capable of measurably reducing the greenhouse gases in the atmosphere. Rather, the motivation is to produce fuels for transportation applications, such as jets and heavy-duty trucks and buses.



The process uses a large wall of fans, known as a contactor, to push air through a liquid that reacts with the carbon dioxide (see "Carbon Capture," November/December 2012). The resulting solution is then put through several processing steps to create a purified stream of carbon dioxide gas, letting the liquid return to the contactor. The recovered carbon dioxide must then be combined with hydrogen to make hydrocarbon fuels. Supported by funding from British Columbia's government, Carbon Engineering plans to install an electrolyzer and obtain hydrogen that it will use to supply fuel for BC Transit buses. That's at least a year down the road.

The system is relatively energy-intensive, which means that low-carbon power generation, most likely solar, will eventually be needed if the technology is to run cleanly. Carbon Engineering, which is backed by a group of investors including Bill Gates, is one of several companies, including the German firm Climeworks, working on carbon capture from ambient air. In the past these technologies have been touted as having the potential to significantly reduce the amount of carbon in the atmosphere, thus slowing down global climate change. For now that's a pipe dream; for one thing, extremely large amounts of air must be moved through such a system to capture a meaningful number of carbon dioxide molecules.

An active market for fuels made with air-captured carbon dioxide would go a long way toward making the economics work out, at least for small-scale systems. Burning the fuel would, of course, release carbon, but unlike the combustion of fossil fuels, it would not add to the total amount of carbon dioxide in the atmosphere. *—Richard Martin*

COURTESY OF CARBON ENGINEERING

TWELVE TOMORROWS

The 2016 edition of MIT Technology Review's science fiction anthology: visionary stories of the near future inspired by today's new technologies.

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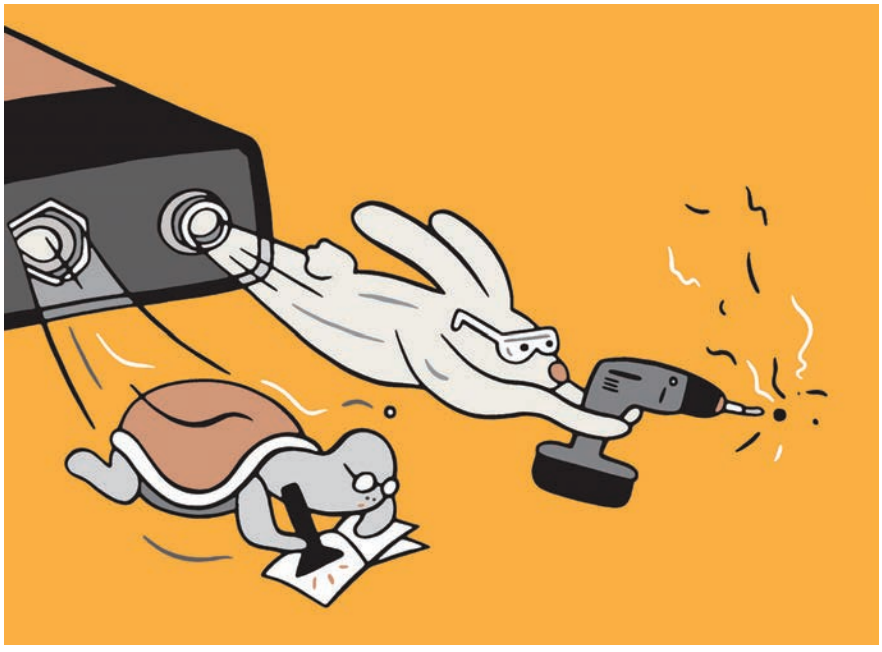
MIT Technology Review

Upfront

Battery Firepower

Microsoft researchers show that batteries with a dash of intelligence might make our devices last longer.



Mobile devices such as tablets and smart watches could get quicker to charge and slower to run out of juice thanks to a new approach to designing batteries from Microsoft researchers.

The battery inside any given gadget today typically has one particular chemical design that defines its capacity and limits how quickly and efficiently it can charge and discharge. Our devices might be much improved if they instead had multiple smaller batteries, each with a slightly different chemical makeup and performance level, says Ranveer Chandra, a principal researcher at Microsoft. Software could then choose how much to charge and discharge a device's different batteries at any moment, depending on what the device was being asked to do—or what it might be expected to do in the future, given a person's typical activity. "This can allow the battery to become a more intelligent, customizable entity," says Chandra.

For example, a phone might have one battery that can efficiently provide a lot of power for an activity such as playing games during your morning subway ride, and a second battery with a lot of capacity that's good at trickling out power over long periods of idling time.

Chandra says that "software-defined batteries," as the researchers call them, could also help drones and electric cars. A car might be able to use cues like the destination punched into its navigation system to figure out how to manage batteries with different properties, says Chandra. Data about the route, inclines, and expected traffic conditions could all help the car use its energy more effectively, he says.

The Microsoft researchers have tested their idea by modifying real mobile devices such as phones and tablets. They altered the software on the devices and linked them to a custom circuit board that could manage four different external batteries. One test was intended to determine how a smart watch could benefit from having a flexible battery in its strap as well as a conventional battery in its body. Bendable batteries are not very efficient at providing a lot of power at once. So the researchers programmed their software to carefully balance the work of the two batteries during a simulated day of activity. In the test, that balancing act extended battery life by more than an hour.

This concept emerged from a research effort at Microsoft that began in 2012 and is aimed at dramatically increasing the battery life of mobile devices. Although software-defined batteries are just a research project for now, Chandra has worked with colleagues from Microsoft product groups working on HoloLens and the Surface tablet.

With battery life a major shortcoming of wearable devices, the idea of software-defined batteries could gain traction in the industry, says Christine Ho, cofounder and CEO at Imprint Energy, a company developing flexible batteries. And being able to combine new battery technologies like Imprint's with older, better-understood ones could make it easier for the newcomers to become commercially successful and change what devices are able to do.

However, putting multiple batteries and extra components and software into devices doesn't come free. "For high-end devices it makes a lot of sense, but it may not be possible for all types," says Ho. "For many wearables they will need to be low-cost, and space is very constrained."

—Tom Simonite

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Go Further

Upfront

Shared Robot Knowledge

A robot at Brown University learned how to perform a task from a very different robot at Cornell University.

The ability to acquire and then share knowledge is a central component of human culture and civilization. A small milestone in the exchange of robot knowledge has now been demonstrated by two bots working in different academic research labs.

Researchers at Cornell University previously devised an online game, called TellMeDave, through which volunteers can help train a robot to perform a task and associate different actions with commands given in everyday language. By guiding the robot through a task, a volunteer trains a machine-learning algorithm so the robot can perform the task again. And this learned behavior is stored in a central repository called RoboBrain, which is accessible to other robots.

Some time ago, through this platform, a type of research robot called PR2 had been taught to perform a number of simple demonstration tasks, including picking up several mugs from a table and placing them on top of upturned bowls. Several hundred miles away, in a lab at Brown University, a different type of robot, called Baxter, has taken what PR2 had learned and used it to figure out how to perform the same task in an entirely different setting.

The work is part of an effort to figure out how robots might share information in useful ways. That could reduce the need for meticulous reprogramming, and it could allow robots to adapt quickly when faced with a new task or an unfamiliar setting. "It's pointing in an interesting direction," says Stefanie Tellex, an assistant professor at Brown University, whose group enabled the Baxter robot to learn. "When you put a robot in a new situation—and in the real world it happens in every room the robot goes into—you somehow want that same robot to engage in autonomous behaviors."

The goal is to eventually enable a robot to translate information for itself.

Speaking at the Bay Area Robotics Symposium, held at the University of California, Berkeley, Ashutosh Saxena, who led the development of TellMeDave and RoboBrain, said that robots will increasingly share information in the future. "We are trying to make robots learn and share knowledge," he said. "Different robots can push and pull knowledge from the [RoboBrain] database."

The key challenge in transferring learning between the robots at Cornell and Brown was that they are physically completely different, which means that low-level commands, such as those specifying the position each joint needs to assume in order to reach for a mug, will not match. Tellex's group had to figure out a scheme that would allow commands to be transferred between the two platforms.

Ultimately, she says, it would be ideal for a robot to figure out how to translate information for itself, based on the way its physical body compares with that of another robot. "This is what we'd all like to do, and this is really a baby step toward that vision," Tellex says. "There are a lot of remaining technical challenges."

Nick Roy, a professor at MIT's CSAIL, says many researchers are interested in enabling robots to share knowledge. One thing making it possible, he says, is increased bandwidth and cloud computing capacity: "As we've gotten the ability to handle more and more data across the Internet, it's become more feasible to have this kind of shared [knowledge] representation. It's something that the robots community has long aspired to." —*Will Knight*

TO MARKET

Light L16

High-end camera

COMPANY:
Light

PRICE:
$1,699

AVAILABILITY:
Summer 2016

The startup Light is building a camera that shoves the picture-taking power of a big DSLR and several detachable lenses into a gadget the size of a narrow paperback. The L16, a rectangular black camera that can capture images of up to 52 megapixels, will squeeze in 16 camera modules with three different focal lengths. Each of the camera modules will have a 13-megapixel image sensor. The cameras will simultaneously snap their own shots from different perspectives when you take a picture, and software will combine them automatically into one image that mimics what you'd get from a DSLR camera with a large lens attached to it. And all for about a third of the cost. —*Rachel Metz*

COURTESY OF LIGHT

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When you think of Italy, what first comes to mind? Most likely, it's some combination of food, fashion, fine wine, and fast cars.

But Italy is equally important for its leadership in machinery, advanced manufacturing, and —most recently—robotics. »

AMICO, the 66-pound humanoid robotic concept from Turin-based manufacturer Comau, offers new levels of flexibility, precision, and speed for work in small spaces.

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HOME TO SOME OF EUROPE'S **MOST ENVIRONMENTALLY EFFICIENT** MANUFACTURING SYSTEMS

Source: Italian Trade Agency and FEDERMACCHINE

According to the Italian Trade Agency and FEDERMACCHINE, the federation of associations representing Italian machinery manufacturers, Italy is:

- Among the world's top three producers of machine parts.
- Among the top five non-U.S. hosts for additive manufacturing technologies.
- Among just five countries worldwide with a manufacturing trade surplus exceeding USD $100 billion.
- No. 2 worldwide in global competitiveness in machinery.
- Home to some of Europe's most environmentally efficient manufacturing systems.

In addition, Italy is No. 2 in the European Union in robot density—that is, the ratio of robots to manufacturing employees, according to the International Federation of Robotics (IFR), a trade association.

"Italy is at a very positive stage, in a very positive period," says Maurizio Forte, U.S. executive director of the Italian Trade Agency, the Italian government organization that promotes the internationalization of Italian companies and provides information, support, and advice to both Italian and foreign businesses. "We are Europe's second-largest manufacturing economy. Unemployment is down; the dollar is strong."

For all those reasons, Italy is fast becoming an attractive destination for businesses seeking innovation partners.

Centuries of Innovation

Italian trade officials acknowledge that Italy's expertise in advanced manufacturing, robotics, and similar areas isn't yet well-known worldwide. As Forte puts it: "People still tend to think of Italy only in terms of consumer goods." But about 4,600 companies are producing industrial machinery and related products in Italy today, employing nearly 180,000 people—a significant percentage of the workforce in a country with a population of just under 60 million. In 2014, total industrial production reached USD $46.5 billion, with nearly three quarters of that represented by exports.

Italy's technology expertise is actually nothing new. "Italy has a centuries-old tradition of designing and building machinery," notes Italian Trade Agency President Riccardo Maria Monti. (Just how far back does that designing-and-building tradition extend? Leonardo da Vinci, one of history's greatest engineers and architects, was already busy developing his many inventions throughout Italy more than 500 years ago.)

Left to right: Maurizio Forte, Arturo Baroncelli, and Alberto Maria Sacchi. Next page: Italian professional basketball player Marco Belinelli, now with the Sacramento Kings, shoots hoops with a Comau Racer robot on an NBA-regulation court.

Today, innovation is baked into the country's business culture, along with another distinctly Italian ingredient: a highly cooperative industrial environment. "There's a very strong tradition of engineering collaboration between companies," says Alberto Maria Sacchi, CEO of the Milan-based Meccano Group. "They believe in creating common platforms to guarantee consistent quality and service in new markets." Not surprisingly, Italy's industrial sector also enjoys tightly coordinated supply chains that evolved from the country's historic practice of clustering entire industries—for instance, shoes, chairs, or mechanical parts—in regional districts, and it boasts a world-class base of system integrators as well.

Entrepreneurism is an additional part of the recipe. "If you meet a typical Italian entrepreneur, you will meet a person who is fully in love with his product and very reactive to new opportunities and new markets," says Sacchi, who is also a board member and past president of FEDERMACCHINE.

Italian manufacturers tend to place high value on building and maintaining strong long-term relationships and providing customized service that can adapt quickly to meet changing market demands, Sacchi adds. "Generally speaking, there is a strong empathetic attitude toward customers. We follow their needs; we are very flexible."

Italy boasts one other competitive advantage: a higher-education network that includes some of the world's oldest colleges. Top technical programs at schools in Milan, Turin, Rome, Pisa, Genoa, and other Italian cities provide the industry with a steady stream of scientists, technologists, and engineers.

"Now we are extending that long history of engineering excellence into next-generation manufacturing," Monti says. "Italian companies are leaders in the use of robotics and advanced manufacturing techniques, and our world-class universities and research centers allow us to keep innovating in these areas."

Innovation in Automation

No question: Industrial robots represent one of today's top global technology trends. About 1.5 million industrial robots are used on the world's factory floors today. Within three years, that number will reach 2.3 million, according to the IFR's latest World Robotics report. In 2014, global robot sales increased by 29 percent over 2013, with the 229,261 units sold representing "by far the highest level ever recorded for one year," according to the report.

In 2014, Italy ranked second in the European Union and seventh worldwide in the number of industrial robots in use—more than 6,200 total, according to the IFR. Italy's robot density ratio of 155 industrial robots per 10,000 manufacturing employees is among the world's highest, and more than double the worldwide average of 66. In Italy, as elsewhere, robot use is growing fastest in the automotive and electronics sectors, but other industries are catching up.

TODAY, INNOVATION IS BAKED INTO ITALY'S BUSINESS CULTURE, ALONG WITH ANOTHER DISTINCTLY ITALIAN INGREDIENT: A HIGHLY COOPERATIVE INDUSTRIAL ENVIRONMENT.

"The industrial robot has become the way—not one way, but *the* way—to manufacture a lot of things," says Arturo Baroncelli, IFR president and business development manager for Comau Robotics, which is among the world's largest producers of robots. (Comau Robotics is a division of Turin-based Comau, a market leader in advanced manufacturing, automation, and service solutions; Comau's parent company is Fiat Chrysler).

What's driving demand? "Robots are able to do things humans can't do," Baroncelli says. For instance, robots can lift heavy objects, reach across long distances, pick and place more than 150 small items per minute, withstand high heat and other conditions harmful to humans, and function around the clock. Advanced robots are programmable; they can function in multiple positions, and they can make decisions. (They can even learn, as shown in a Comau Robotics commercial in which professional basketball player Marco Belinelli of the Sacramento Kings teaches a Comau Racer robot to shoot hoops.)

Baroncelli and others emphasize that industrial robots aren't eliminating jobs; instead, they're typically taking over work that's too difficult, dangerous, or unpleasant for humans to do. In addition, robots do best when performing the same functions over and over; assigning them to highly repetitive tasks can free up human employees for more skilled work. Finally, experts say, growing demand for automation is actually generating robotics-related jobs in areas ranging from engineering to service and repairs. "We still need people to invent things, to maintain things," Baroncelli says. Put another way: Human innovation—historically among Italy's greatest strengths—will continue growing right along with its robotics industry.

MIT TECHNOLOGY REVIEW
VOL. 119 | NO. 1

A Change of Mind

Diana Bianchi championed tests that find Down syndrome early in pregnancy. Now can she find a way to treat it?

By Bonnie Rochman

Photographs by Leonard Greco

Jerome Lejeune is the Frenchman who discovered the chromosomal error responsible for causing Down syndrome, half a century ago. Lejeune, who died in 1994, was a devout Catholic, and he was aghast when he realized his discovery would lead to prenatal tests and abortions. In his view, this was eliminating the patients instead of treating them. Someday, he felt certain, a cure would be found. "We will beat this disease," he wrote. "It's inconceivable that we won't. It will take much less intellectual effort than sending a man to the Moon."

A framed letter from Lejeune hangs outside the office of Diana Bianchi, who is arguably America's best-known neonatal geneticist. She is celebrated because of the role she's played in introducing noninvasive prenatal testing and documenting its accuracy and drawbacks (see 10 Breakthrough Technologies 2013: "Prenatal DNA Sequencing"). The blood tests she researches are an improved way to detect chromosomal disorders such as Down syndrome, also called trisomy 21, the most common genetic birth defect causing intellectual disability. Since the tests debuted in 2011, according to calculations from Bianchi's research institute for maternal and fetal medicine at Tufts University, more than two million have been performed.

Diana Bianchi leads a search for drugs that could treat Down syndrome.

The tests are highly accurate and can detect Down syndrome as early as the first trimester. But the medical options in the face of a positive result remain as starkly limited as they were in Lejeune's day: continue the pregnancy and have a child with multiple disabilities, or don't. Sixty to 70 percent of women who receive a prenatal diagnosis of Down syndrome in the United States opt for abortion, according to a peer-reviewed article in the journal *Prenatal Diagnosis*.

That's why Bianchi's role in the rapid spread of noninvasive testing has also made her the target of critics, particularly people with Down syndrome and their parents, who say they are happy as they are. To those who have posted criticisms of Bianchi on the Web or personal attacks on her hospital's Facebook page, the goal of improved tests can only be fewer people with Down syndrome.

To those who will listen, though, Bianchi has been advancing an entirely different scenario. She says that early testing will lead to the first treatments for Down syndrome. With the ability to routinely detect the syndrome as early as 10 weeks of pregnancy, she says, the tests are creating the chance to develop drugs that address cognitive deficits in the womb. "Plenty of people think that their children with Down syndrome are perfect the way they are," says Bianchi. "But there are also plenty of people who, if given the choice, would want to attempt to treat their children." Critics of testing "don't know the complete picture," she says. "They don't realize there is another half to the equation."

On the day I visited Bianchi at her lab in Boston's Chinatown, she was wearing a soft teal turtleneck and a taupe blazer. She guided me to her lab, where we slipped on gauzy elasticized hair coverings, long-sleeved gowns, booties, and gloves before viewing brown mice, some with a condition mimicking Down syndrome. Some of their mothers had been treated with a common drug or supplement (Bianchi said it's possible they could ultimately test combinations of drugs, but for now they're testing them one by one). It's an attempt to enhance the growth of the young mice's neurons during a critical stage of brain development.

Bianchi's drug search remains a relatively small effort, focused on safe and already-approved drugs that could be used in utero. Others are also beginning to look at treatments. A Texas hospital is readying a trial of Prozac in pregnant women whose fetuses have Down syndrome, and a scientist at Cornell is investigating supplementation with choline, an essential nutrient. This past summer in Paris, Bianchi led what she calls a "really historic" session at the Trisomy 21 Research Society meeting, devoted to prenatal treatments. Just stirring interest in treatment feels like a fairly big achievement, she says.

Bianchi, now 60, was a college student in 1973 when she wrote to Lejeune to ask for an internship. She says she forgot about the correspondence until 2012, when she unearthed a handwritten response from him that she'd tucked away in a box four decades ago—the one now displayed outside her office. In it, Lejeune complimented her French and offered his "cordial sympathies" that there was no place in his lab. She says rediscovering the letter as she began working on a treatment felt symbolic: "I thought, 'This is a sign.' It shows that I have been thinking about this for a while. It was a sign that this was meant to be."

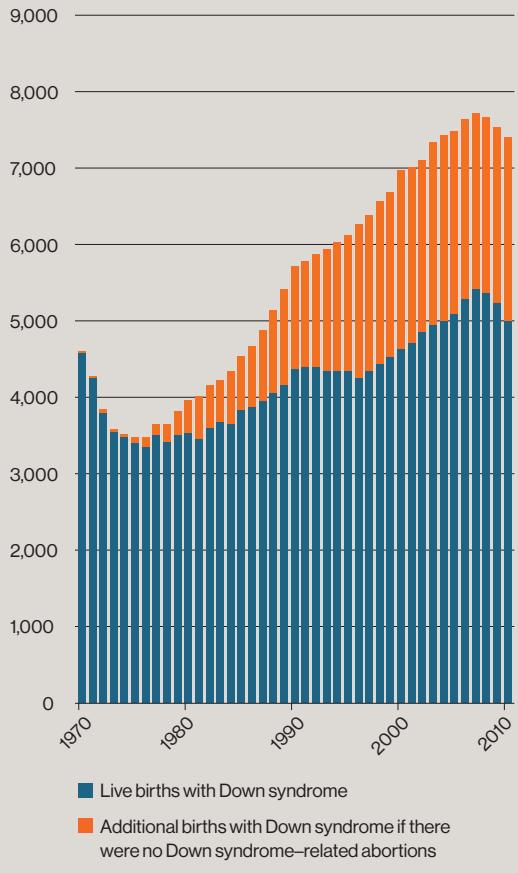
One convert to Bianchi's campaign is Mark Bradford, father of a son with Down syndrome and president of the Jerome Lejeune Foundation USA, the American arm of a Paris-based group. He says the foundation's view remains that noninvasive prenatal testing is "an incredible threat to the Down syndrome community," but he has come to believe that Bianchi will develop "an antidote" to that threat and is helping to fund her search for a drug. Bianchi says Bradford was the first member of the polarized Down syndrome community to listen to her ideas. "I think one day she will prove to have been a heroine in that her advancement of [noninvasive tests] will be the gateway to early therapy and will save countless lives," says Bradford. "She is very unjustly and harshly criticized for her work by people who can't see [past] prenatal diagnosis to its future benefit."

Early as possible

The nucleus of a normal human cell contains 46 chromosomes. But in people with Down syndrome there are 47: an error that occurs in sperm or egg cells before fertilization results in an added copy of the 21st chromosome. The extra chromosome, which harbors more than 200 protein-coding genes, is transmitted to every cell in a person's body. That results in intellectual delays, heart problems, and other conditions that shorten life span, and physical features such as eyes that slant upward. The pervasive nature of the disorder is what's always made it difficult to imagine how it could be treated.

And for a very long time, scientists stopped wondering. They worked on better tests to detect the disorder prenatally, but as Bianchi acknowledges, they paid virtually no attention to what was actually occurring in Down syndrome pregnancies. Bianchi now thinks there is a window of opportunity when the brain development of a fetus with Down syndrome begins to diverge from the normal path. At about 15 weeks of pregnancy, she says, the brain starts to grow more slowly than usual. In the most severe cases, the fully developed brain can end up 75 percent as big as that of a typical newborn. Perhaps

Babies born with Down syndrome in the U.S.
A substantial number of pregnancies are terminated after the diagnosis.



Any kind of fetal medicine is still very unusual. Only one drug, the vitamin folic acid, is taken regularly to steer the course of prenatal development.

this slowdown could be minimized if the mother were given the appropriate drug as soon as a diagnosis was made. "You want to address the problem as early as it can be detected," says Tarik Haydar, who runs the Laboratory of Neural Development and Intellectual Disorders at Boston University and collaborates with Bianchi.

Neurogenesis—the creation of neurons—occurs largely in the womb. Between birth and puberty, neurons mature and go through a process of myelination, or insulation, and formation of synapses, or connections. Neurogenesis continues too, but at a snail's pace compared with the rapid-fire production in the womb, where—on average—300 million neurons are created per day in early pregnancy. "There is still something you can do after birth, but if you really hope to rescue neurogenesis, you have to do it prenatally," says Renata Bartesaghi, a professor in the Department of Biomedical and Neuromotor Sciences at the University of Bologna.

Bianchi has called this possibility "fetal personalized medicine." Any kind of fetal medicine is still very unusual, though. There are a few complex fetal surgeries to repair birth defects, but only one drug, the vitamin folic acid, is taken regularly to steer the course of prenatal development. If women have the supplement in their bodies from conception through the first weeks of pregnancy, their babies are protected from neural tube defects including spina bifida, a malformation of the spinal cord. Folic acid points to the importance of timing. If taken at the right time, it prevents a serious error in development. But no amount of folic acid will help after development has run its course.

Bianchi began testing drugs for Down syndrome on mice in 2011, theorizing that it might be possible to change the brains of babies with something as simple as folic acid. Her thinking had changed when she learned of efforts to treat fragile X syndrome, another cause of intellectual impairment, and as new tools to investigate development became available—including the noninvasive tests, which launched that year. "I realized that research in neurocognition was changing rapidly," she says.

The physical differences in Down syndrome can be seen in an ultrasound: more fluid accumulation at the back of the neck, or an absent nasal bone. But one of Bianchi's first steps was to try to find a molecular signature of the disorder by collecting amniotic fluid from pregnant women, in order to measure the "transcriptome" of fetal cells—a readout of which genes are turned on or off. She found about 300 genes that behaved differently in Down syndrome, and most of them were not on chromosome 21. That underscored the complexity of the disease, but it also provided what Bianchi says is her key finding.

AMERICAN JOURNAL OF MEDICAL GENETICS

The gene patterns in fetuses with Down syndrome suggested high levels of oxidative stress, an indication that cells were being damaged. "We all have oxidative stress," says Bianchi, "but our systems take care of it. Is there more in a Down syndrome fetus, or can they just not handle it?" Bianchi's hypothesis is that the abnormal biochemical environment is knocking out stem cells that would otherwise be making new neurons.

Bianchi has been searching for drugs that can reduce oxidative stress and possibly "rescue" neurogenesis, at least in part. It is the sort of early-stage prospecting that a drug company might do, if any were pursuing a prenatal therapy for Down syndrome. Her search has been very conservative, restricted to drugs that are already sold for other purposes and have good safety records. Her team located candidate drugs using a database maintained at another Boston-area research center, the Broad Institute, which holds records of how 1,300 different compounds affect the transcriptome of human cells grown in the laboratory. That database kicked out lists of compounds whose effects on gene activity are essentially the reverse of what's seen in Down syndrome and might counteract it.

From those 1,300 drugs and chemicals, Bianchi's group narrowed the list to 10. In her lab, the compounds are mixed into food and fed to mice, including pregnant females carrying pups, about half of whom have a condition that mimics Down syndrome.

Bianchi and postdoctoral researcher Faycal Guedj demonstrated for me how they test seven-day-old mice, some healthy and others with the rodent version of Down syndrome (the researchers conceal from themselves which are which). With a gloved hand, Guedj catches a brownish mouse that seems unusually small, just 53 millimeters.

In one test, the mouse takes 17 seconds to flip from back to belly, struggling to get its right foot out from beneath its body. In another test, it musters only enough strength to hang from a metal wire for three seconds. Bianchi guesses it is a Down syndrome mouse. A second mouse manages to hold on for nearly eight seconds and deftly flips over in four. "See how quick it was," she marvels.

Guedj, who is from Algeria, was six when his sister, Imene, was born with Down syndrome. She can't read, and her speech is limited to a few words that she feels confident using ("I want chocolate" is a familiar sentence). Guedj wonders how Imene's life would have

Top: A research assistant at Tufts performs a genetic test on mice with a condition similar to Down syndrome. Bottom: Equipment helps search for drugs that might treat the condition in the womb. Right: Researcher Faycal Guedj is a postdoc in Bianchi's lab.

In 2013 researchers made headlines by successfully "silencing" the extra copy of chromosome 21 in human cells from a patient with Down syndrome.

been different if she'd had the option of treatment in utero. "You see your nephews and nieces growing up and her stuck at a certain level," he says. "We missed the opportunity of treating her early."

Radical measures

Of the 10 compounds that Guedj and Bianchi identified, two seem particularly promising. One is apigenin, which is found in plants, but Bianchi won't yet publicly identify the other. Each has shown therapeutic, but not groundbreaking, effects. No matter how successful the drugs might be, Bianchi does not expect them to change the physical appearance of people with Down syndrome; nor is it likely that they'd reduce the incidence of heart defects, which occur in about half of babies with the disorder. "From what I've seen so far, there is no magic bullet where you take the drug and everyone is cured," she says.

Some researchers, however, are contemplating more radical measures. Jeanne Lawrence, a professor in the Department of Cell and Developmental Biology at the University of Massachusetts, made headlines in 2013 when she succeeded in "silencing" the extra copy of chromosome 21 in human cells from a patient with Down syndrome. She did so by using gene editing to splice in a gene for an RNA coating that painted the extra chromosome with a molecular block so that none of its 250 genes produced any proteins.

To Lawrence, this is a first step toward a "chromosome therapy" that would make use of genetic engineering in the womb. "Multiple pathways are perturbed, and one drug is not enough to fix them," she says. "If you can silence the 250 genes, you don't need a drug."

Fetal gene engineering probably remains far off. But the first prenatal tests of drugs in humans are likely to start soon. A group of physicians at University of Texas Southwestern in

A Time Line of Down Syndrome

1866
Physician J. Langdon Down uses ethnic characteristics to classify the intellectually handicapped residents of a British asylum, resulting in the term "Mongolism."

1946
Life expectancy of someone with Down syndrome is 12 years. Famed pediatrician Benjamin Spock recommends that such babies be institutionalized at birth.

1959
Studying human cells with a microscope, Jerome Lejeune and French colleagues discover the cause of Down syndrome. It is an extra copy of chromosome 21.

1961
Biomedical researchers write a letter to the *Lancet* objecting to the term "mongolism." They propose "Down's syndrome" or "trisomy 21" as an alternative.

1974
First mouse model of Down syndrome is developed in West Germany, speeding research.

1976
Prenatal testing using amniocentesis becomes common in the United States, leading to the first abortions for Down syndrome.

1993
The International Down Syndrome Federation is formed to promote human rights for people with the syndrome.

2006
National Institutes of Health funding for Down syndrome reaches a low of $14 million out of a $28.5 billion budget, or 0.0005 percent. Down syndrome remains the most common cause of intellectual disability at birth.

2011
U.S. company Sequenom launches the first noninvasive blood test for Down syndrome, quickly creating a multimillion-dollar market aimed at consumers.

2011
At least 10 drug treatments are shown to partly correct learning and memory deficits in Down syndrome mice, spurring interest in clinical trials.

2015
Physicians in Texas plan to launch the first study of a drug for women carrying a Down syndrome pregnancy. It is the antidepressant Prozac.

Dallas is on the verge of launching a small study to give fluoxetine, the generic form of Prozac, to women who have chosen to continue their Down syndrome pregnancies, and then to the children for the first two years of their lives. The idea springs from work by Bartesaghi, the researcher in Bologna, who has reported remarkable results administering fluoxetine to a different strain of mice with a condition that mimics Down syndrome. The antidepressant boosts the availability of serotonin, a neurotransmitter important in the development of neurons. In 2014 in the journal *Brain*, Bartesaghi reported that the affected mice had a normal number of neurons after birth and 45 days later. The mice were given a memory test. "They acted the same as normal mice," she says. "They were perfect."

Bianchi says the Italian mouse data are impressive, but she is concerned about giving large doses of Prozac—the trial calls for as much as 80 milligrams a day—to women who have no psychiatric disorder. Safety concerns will always be an obstacle to fetal treatment. "We would feel horrible if we came up with what's in theory the perfect treatment and then in clinical trial it caused harm to mother and baby," she says.

Nor can studies on mice reliably predict what will happen to a person's brain. Melissa Parisi, chief of the Intellectual and Developmental Disabilities Branch at the National Institute of Child Health and Human Development, finds Bartesaghi's and Bianchi's work "very promising" but thinks a treatment could be far away. "We've cured ALS in mice a thousand times, but we still don't have a treatment in humans," says Parisi. "Humans are much more complicated."

Help my child

When I asked Bianchi if her real goal is to decrease the rate of abortion for fetuses with Down syndrome, she deflected the question. "Our goal is to hopefully improve neurocognition and, in doing so, provide expectant couples with a message of hope," she says. "What people decide to do with that information is their business."

But if Bianchi or others do succeed with a drug therapy, the option would present new and complicated choices for expecting parents and for their doctors. Those who today would be inclined to have an abortion might reconsider. Other parents might question what it means to try to alter cognition. "When you first discover you are having a baby with Down syndrome, your gut reaction is 'This is a problem—how can we fix it?'" says Amy Julia Becker, who has a daughter, Penny, with the condition. Becker, who lives in Connecticut and writes frequently about Down syndrome, says her attitude has changed: "Penny is almost 10. I don't see

GLOBAL DOWN SYNDROME FOUNDATION

A pregnant mouse at the Mother Infant Research Institute at Tufts Medical Center.

it any longer as a problem that needs fixing." She would find it easier to support a treatment for the heart problems that affect many people with Down syndrome, but "the cognition piece? I'm kind of neutral on that," she says. "There is a sense that cognition is more interwoven than heart defects with who you are."

But many parents would be ready to leap for a promising drug. "I had a lot of fear that I wasn't doing everything I could be doing," says Liz O'Hara, an elementary school teacher from Connecticut, of her pregnancy with her son Michael, who was born in July and diagnosed prenatally with Down syndrome. She took megavitamins and choline supplements, tried acupuncture, and cut down on gluten and dairy. She decided against taking Prozac for fear of side effects, but she would have welcomed a treatment that had been well studied and declared safe. "Part of me would do anything to … I don't want to say fix my child, but help my child," she says.

So far, fetal therapies have been reserved for critical cases—a cardiac surgery to save a baby's life, for example. Haydar says he and Bianchi have talked over the "significant social hurdles" of trying to intervene for any reason other than to keep the child from dying. "There's obviously a challenge in talking about fetal therapy," he says. "You don't want to go playing around with a developing fetus, potentially affecting that individual and their family for the rest of their life, unless you have to do it to save the baby's life."

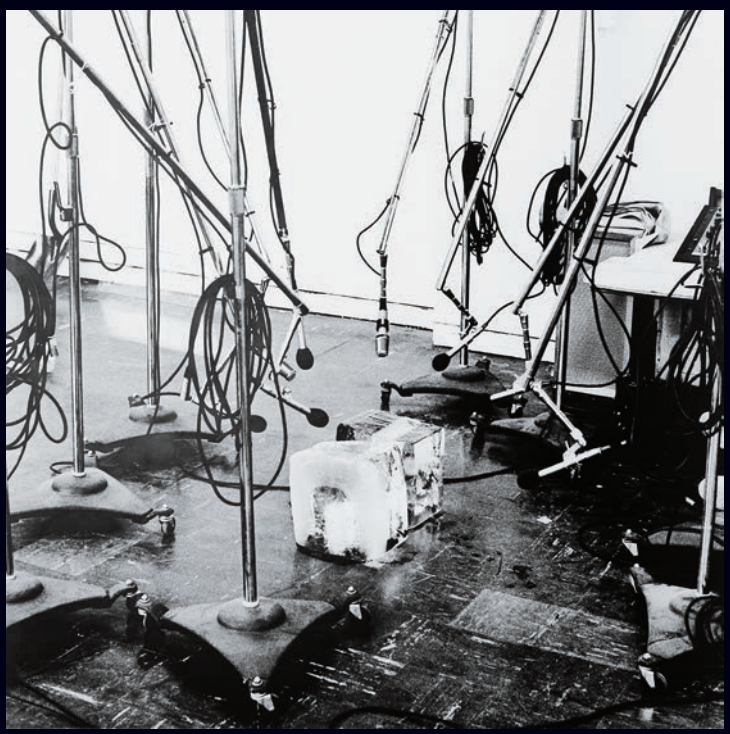
Haydar says he and Bianchi imagine how they would counsel parents. For example: A woman is informed in a doctor's office that her fetus has Down syndrome, with its accompanying likelihood of intellectual disabilities and heart defects. Then the doctor would say: "There is a new breakthrough, a pill that will reduce the likelihood of intellectual disability by 50 percent or 80 percent," says Haydar. "That's the best-case scenario. But any time you enter into a conversation about prenatal anything, those conversations are touchy, because there is a vast array of feelings that people have. Diana and I talk about this a lot."

Bianchi says she regularly receives e-mails inquiring about prenatal treatment. For people undecided about raising a child with Down syndrome, the promise of a drug that improves thinking might tip the scales in favor of continuing the pregnancy. "My hope is that it will change the conversation," she says. "It gives the message that we are not giving up on your child, that your child has options to get better."

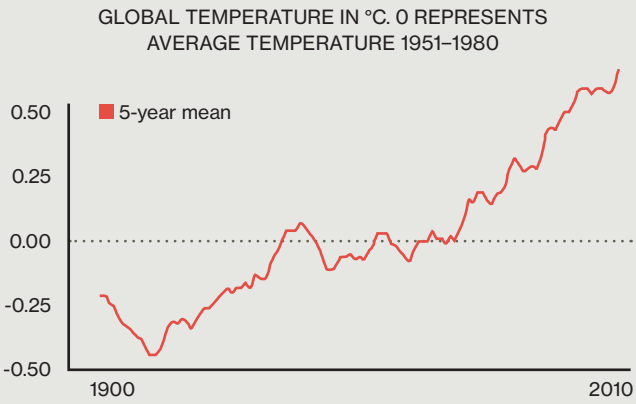
For people undecided about raising a child with Down syndrome, the promise of a drug that improves thinking might tip the scales in favor of continuing the pregnancy.

Bonnie Rochman is a health and science writer in Seattle who is working on a book about how genetics is reshaping the experience of childhood.

What’s Next?



It’s too late to stop climate change from happening.
But we can begin to limit the damage
and slow it down.



The pledges from countries around the world on how they intend to cut emissions of carbon dioxide and other greenhouse gases make for remarkable reading. It's true that even if they are fully implemented, these pledges—submitted as the nations prepared for the Paris climate conference beginning in late November—will fall dangerously short of keeping the average global rise in temperature below 2 °C. Still, they signal an international consensus about the dangers of climate change, and they communicate a sense of how urgent it is to transform our energy infrastructure.

Many of the nations' plans contain poignant descriptions of damage that is already happening. Says the document from Bangladesh: "Extreme temperatures, erratic rainfall, floods, drought, tropical cyclones, rising sea levels, tidal surges, salinity intrusion and ocean acidification are causing serious negative impacts on the lives and livelihoods of millions of people in Bangladesh, and are gradually offsetting the remarkable socio-economic development gained over the past 30 years, as well as jeopardising future economic growth."

These fears are supported by research into the social and economic effects of climate change (see page 70). But we know what needs to be done. It is essential that a price be put on carbon emissions to account for the real cost of burning fossil fuels. And we need to increase our funding both for research into new energy sources (see page 84) and for widespread deployment of promising technology (see page 51). Meanwhile, improvements in agriculture, such as drought-resistant crops, and in other areas of technology can help us adapt to climate change.

In 2006, *MIT Technology Review* ran a cover story titled "It's Not Too Late." Now, despite a decade of inaction, it is still not too late to lessen the damage. It will be an immense and expensive undertaking to transform our energy infrastructure and help those most harmed by the changing climate. And, as climate scientist Ken Caldeira reminds us (see page 40), we must also change our attitudes and stop allowing carbon waste to be dumped into the air. —*The Editors*

Paul Kos
The Sound of Ice Melting
1970

COURTESY OF PAUL KOS AND ANGLIM GILBERT GALLERY; TEMPERATURE DATA: NASA


CO2 BACK BY POPULAR DEMAND
MY CARBON FOOTPRINT IS BIGGER THAN YOURS
I'D RATHER BE POLLUTIN
DUMP Nature
Are we DEAD yet?
CAUTION! THIS CAR STOPS & IDLES

STOP EMISSIONS!

A climate scientist argues that public attitudes must change so that it is no longer acceptable to dump carbon dioxide in the sky.

By Ken Caldeira

Many years ago, I protested at the gates of a nuclear power plant. For a long time, I believed it would be easy to get energy from biomass, wind, and solar. Small is beautiful. Distributed power, not centralized.

I wish I could still believe that.

My thinking changed when I worked with Marty Hoffert of New York University on research that was first published in *Nature* in 1998. It was the first peer-reviewed study that examined the amount of near-zero-emission energy we would need in order to solve the climate problem. Unfortunately, our conclusions still hold. We need massive deployment of affordable and dependable near-zero-emission energy, and we need a major research and development program to develop better energy and transportation systems.

It's true that wind and solar power have been getting much more attractive in recent years. Both have gotten significantly cheaper. Even so, neither wind nor solar is dependable enough, and batteries do not yet exist that can store enough energy at affordable prices to get a modern industrial society through those times when the wind is not blowing and the sun is not shining.

Recent analyses suggest that wind and solar power, connected by a continental-scale electric grid and using natural-gas power plants to provide backup, could reduce greenhouse-gas emissions from electricity production by about two-

thirds. But generating electricity is responsible for only about one-third of total global carbon dioxide emissions, which are increasing by more than 2 percent a year. So even if we had this better electric sector tomorrow, within a decade or two emissions would be back where they are today.

We need to bring much, much more to bear on the climate problem. It can't be solved unless it is addressed as seriously as we address national security.

Daunting math

In November, a hurricane-strength cyclone smashed into Yemen, in the Arabian Peninsula, for the first time in recorded history. About a week before that, a hurricane with the most powerful winds ever measured slammed into the Pacific coast of Mexico.

Unusually intense storms such as these are a predicted consequence of global warming, as are longer heat waves and droughts and many other negative weather-related events that we can expect to become more commonplace. Already, in the middle latitudes of the Northern Hemisphere, average temperatures are increasing at a rate that is equivalent to moving south about 10 meters (30 feet) each day. This rate is about 100 times faster than most climate change that we can observe in the geologic record, and it gravely threatens biodiversity in many parts of the world. We are already losing about two coral reefs each week, largely as a direct consequence of our greenhouse-gas emissions.

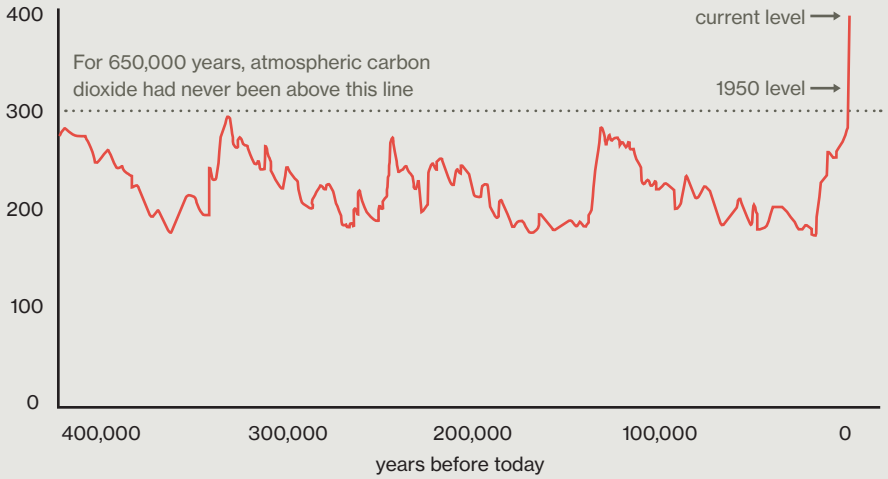
Recently, my colleagues and I studied what will happen in the long term if we continue pulling fossil carbon out of the ground and releasing it into the atmosphere. We found that it would take many thousands of years for the planet to recover from this insult. If we burn all available fossil-fuel resources and dump the resulting carbon dioxide waste in the sky, we can expect global average temperatures to be 9 °C (15 °F) warmer than today even 10,000 years into the future. We can expect sea levels to be about 60 meters (200 feet) higher than today. In much of the tropics, it is possible that mammals (including us) would not be able to survive outdoors in the daytime heat. Thus, it is essential to our long-term well-being that fossil-fuel carbon does not go into our atmosphere.

If we want to reduce the threat of climate change in the near future, there are actions to take now: reduce emissions of short-lived pollutants such as black carbon, cut emissions of methane from natural-gas fields and landfills, and so on. We need to slow and then reverse deforestation, adopt electric cars, and build solar, wind, and nuclear plants.

But while existing technologies can start us down the path, they can't get us to our goal. Most analysts believe we should decarbonize electricity generation and use electricity for transportation, industry, and even home heating. (Using electricity for heating is wildly inefficient, but there may be no better solution in a carbon-constrained world.) This would require a system of electricity generation several times larger than the one we have now. Can we really use existing technology to scale up our system so dramatically while markedly reducing emissions from that sector?

Solar power is the only energy source that we know can power civilization indefinitely. Unfortunately, we do not have global-scale electricity grids that could wheel solar energy from day to night. At the scale of the regional electric grid, we do not have batteries that can balance daytime electricity generation with nighttime demand.

CONCENTRATION OF CARBON DIOXIDE IN THE ATMOSPHERE
IN PARTS PER MILLION



DATA FROM NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

We should do what we know how to do. But all the while, we need to be thinking about what we don't know how to do. We need to find better ways to generate, store, and transmit electricity. We also need better zero-carbon fuels for the parts of the economy that can't be electrified. And most important, perhaps, we need better ways of using energy.

Energy is a means, not an end. We don't want energy so much as we want what it makes possible: transportation, entertainment, shelter, and nutrition. Given United Nations estimates that the world will have at least 11 billion people by the end of this century (50 percent more than today), and given that we can expect developing economies to grow rapidly, demand for services that require energy is likely to increase by a factor of 10 or more over the next century. If we want to stabilize the climate, we need to reduce total emissions from today's level by a factor of 10. Put another way, if we want to destroy neither our environment nor our economy, we need to reduce the emissions per service provided by a factor of 100. This requires something of an energy miracle.

Phase change

Most of the growth in emissions this century is expected to come from the world's developing economies, eager to give their impoverished populations basic health care, education, and meaningful work. Can we in the rich world really ask that people in poor countries allow another child to go hungry or another person to die from a treatable disease rather than use fossil fuels to power their economic growth? We can say that the richest countries should pay the cost differential between carbon-polluting and non-carbon-polluting energy systems for the poorer countries, but right now we can't even get people in most of the rich countries to pay this cost differential for themselves.

How can we get environmentally friendly energy systems that can compete on price with coal or natural gas? We need more incentives. The cost reductions in wind and especially solar over the past decade stemmed mainly from many small process improvements that came about as these technologies were more widely deployed. But many near-zero-emission technologies will cost more than coal or natural gas. Unless there is a tax or price on carbon dioxide emissions, there will be no markets for the innovations that a research and development effort can provide. While there is much merit to the idea of a revenue-neutral carbon tax, it would make sense to allocate some of that tax revenue to clean-energy R&D.

Some people hope we might develop technologies that could remove the carbon dioxide we have emitted into the atmosphere. It's feasible, but it seems to me to be a technological pipe dream. It is always going to be easier and cheaper to avoid making a mess than to clean up one we have already made. It is easier to remove carbon dioxide from a smokestack, where the exhaust is 10 percent carbon dioxide, than from the atmosphere, which is 0.04 percent carbon dioxide. Sure, planting trees and spreading biochar—a soil enhancer that sequesters carbon—may be good things to do; we just shouldn't fool ourselves into believing that doing those things will solve our climate problem.

Despite all these reasons for despair, I am hopeful. What leads me to believe that humanity can solve such a thorny problem requiring collective action on a global scale?

When the Constitution of the United States of America was written, it seemed inconceivable that people would be released from slavery or that women would vote. Just a few years before gay marriage became the law of the land, it would have been impossible to predict such a sweeping change in social attitudes. For us to even have a chance of addressing the climate problem, we'll need another huge change in public attitudes. It will need to be simply unacceptable to build things with smokestacks or tailpipes that dump waste into the air. This change could happen.

The agreements made in Paris will be helpful, but they're like changing over to compact fluorescent lightbulbs: nice, but insufficient to the scale of the task. However, the attention brought to the climate problem at the highest levels of government represents an important step toward a social tipping point—to that phase change when we decide collectively that we are not going to use the sky as a waste dump.

Our children's children will look back on us and ask: "How could everyone have continued using the sky as a waste dump even after everyone knew?" Let's hope they can add, "Well, at least everybody woke up and stopped doing it."

Ken Caldeira is a climate scientist in the Department of Global Ecology at the Carnegie Institution for Science at Stanford University.

Witnessing Climate Change Everywhere

On an Instagram account called everydayclimatechange, the photographer James Whitlow Delano curates pictures that document causes and effects of global warming and responses to it.





Top row, from left: solar panels and passive solar heating systems on traditional homes in India; Kuala Lumpur, Malaysia, cloaked in smog from fires in forests that are being burned to clear land for agriculture; women biking near a coal-powered factory in China. Bottom row: a smoggy view of Chongqing, China; workers on an oil-drilling platform off the Niger Delta in the Atlantic Ocean; residents of an atoll in Papua New Guinea using shells to rebuild a sea wall on an eroded beach. Opposite page: a man from the Niger Delta prepares to board an oil rig in a protest.

LEFT, TOP ROW: ASHLEY CROWTHER. CHARLES PERTWEE. BERNARDO DE NIZ. BOTTOM ROW: TIMOTHY FADEK. ED KASHI. JEREMY SUTTON-HIBBERT; RIGHT: ED KASHI


KEEP OFF
Fear Not
HOLY PARADISE

LEFT: MICHAEL ROBINSON CHÁVEZ; RIGHT, TOP ROW: RODRIGO BALEIA; MIDDLE ROW: KATHARINA HESSE, JEREMY SUTTON-HIBBERT; BOTTOM ROW: JAMES WHITLOW DELANO, RODRIGO BALEIA

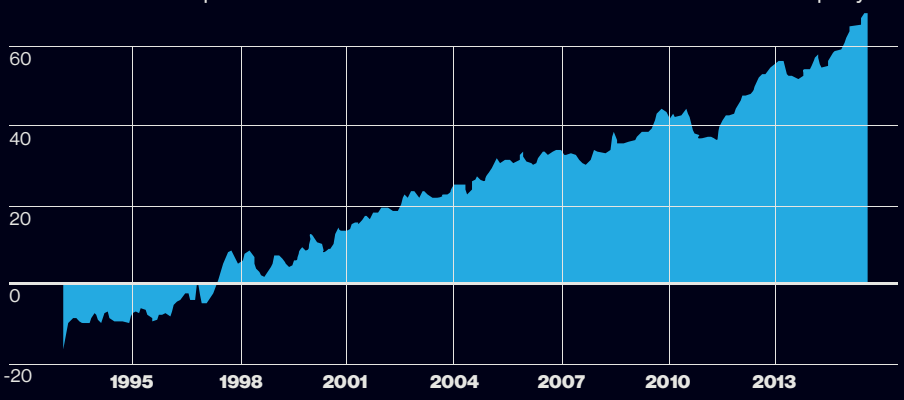
Opposite page: a gold miner next to a sooty glacier in Peru. Top row, from left: land being cleared with fire for farmers and ranchers in Brazil; the Rio Negro, an Amazon tributary, at a record low level in Manaus, Brazil. Middle row: a coal ash disposal site in Inner Mongolia; wind turbines near monuments outside Jaisalmer, India; a clear-cut rain forest in Sumatra. Bottom row: a dump in Phnom Penh, Cambodia, where gas emitted by decomposing trash starts fires; a flooded settlement in Brazil.

The Evidence

Oceans are rising, Antarctica is losing its ice sheets, and the lower atmosphere is heating up. Satellite data (bottom) shows the atmosphere is warming at its lowest layer (the troposphere), while the stratosphere, which begins around 10 kilometers above the ground, is cooling. Scientists say this is consistent with the greenhouse effect.

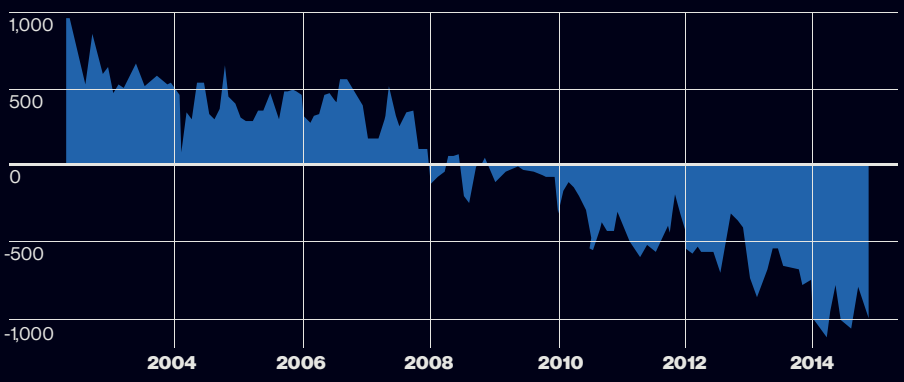
Sea level change in millimeters
Satellite data 1993–present

Rate of change
+3.24 mm per year

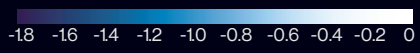


Antarctica's ice sheet in billions of metric tons
Since 2002

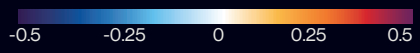
Rate of change
-134 billion metric tons per year

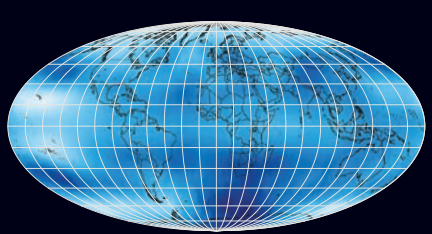


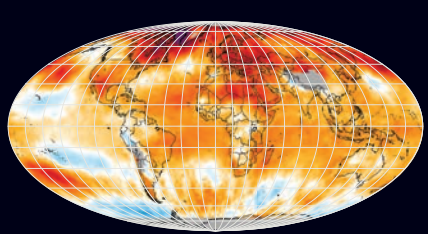
Lower Stratosphere
1979–2013 trend
°C per decade



Lower Troposphere
1979–2013 trend
°C per decade







The Impacts

The changes are already affecting food production, and the economic and health-related costs are expected to be massive.

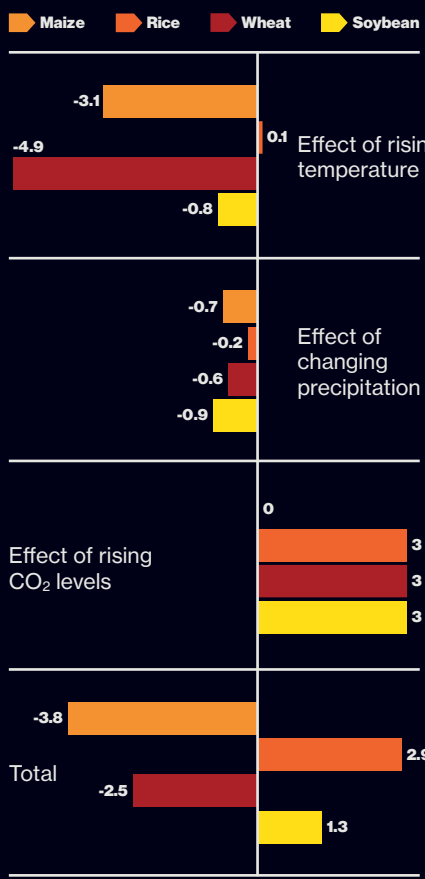
5,000,000

Approximate number of deaths the World Health Organization expects climate change to cause between 2030 and 2050, from malnutrition, malaria, diarrhea, and heat stress.

$2 billion to $4 billion

Estimated annual health-related costs of climate change by 2030.

Agriculture costs
Estimates of climate-related impacts on global crop yield (percent change, 1980–2008)



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A Sensible Climate Policy

Here's a smart way for us to limit carbon emissions and keep global warming below 2 °C.

By Richard Martin

JOOST SWARTE

International climate-change negotiators are focused on keeping global warming at or below 2 °C above historical levels—the limit beyond which the U.N.'s Intergovernmental Panel on Climate Change says the consequences of global warming will become catastrophic. But even though negotiators may have finally made some progress on agreements to reduce emissions, there is a big problem: we're already about halfway to the 2 °C threshold. In October, for example, the warmest October in 135 years of record-keeping, the global average temperature was 1.04 °C warmer than the preindustrial reading. It was no aberration: 2015 is almost certain to have been the warmest year on record, surpassing the previous record set in 2014.

Even as flocks of jets began descending upon Paris for the latest talks, the delegates could see that the consequences of global warming had been setting in fast. Ice sheets in Greenland and Antarctica are shrinking with unexpected speed, Arctic sea ice is disappearing faster than forecast in computer models, and circulation patterns over vast swaths of the planet's oceans are being disrupted. "The more we learn, the more we see that these processes are happening more quickly than we anticipated," says Noah Diffenbaugh, a professor of earth system science at Stanford.

These trends highlight the uncertainty of climate models and the somewhat arbitrary nature of the threshold set by the U.N. panel: the fact is that no one really knows how high the global average temperature will get once the accumulated carbon in the atmosphere stays above 400 parts per million (a level it reached, on a monthly average basis, for the first time last March)—nor what the consequences for humanity will be in a world that is 2 °C hotter than it was in the preindustrial era. And even if we do accept the goal of keeping warming below 2 °C, we still don't know what will have to happen to carbon dioxide emissions to make that possible.

According to a 2014 report from the U.N. Environment Program, the total maximum amount of additional carbon that can be emitted without raising the average temperature by more than 2 °C is about 1.1 trillion metric tons. (In 2014 the world produced 35.9 billion metric tons of carbon.) But that is only an estimate.

So how do you formulate international climate policy given the scientific uncertainties? A number of experts are calling for a self-adjusting policy mechanism that establishes a simple formula for progressive emissions cuts based on empirical data, rather than limits set years in advance. By responding to what's already happened, rather than what scientists conclude is likely to happen, such a system would, at least in theory, sidestep the uncertainty of climate forecasts.

This new approach took form in an August 2015 paper published in *Nature Climate Change* by a group of researchers headed by Myles Allen, a professor of geosystem science at the University of Oxford, and Friederike Otto, a lecturer in physical geography at Oxford and a research fellow at the Environmental Change Institute. The paper, titled "Embracing Uncertainty in Climate Change Policy," argued that a flexible, self-correcting system would be "anti-fragile," in that "uncertainty and changes in scientific knowledge make the policy more successful by allowing for trial and error at low societal costs."

Think of the U.S. Federal Reserve Bank. The Fed doesn't set interest rates far into the future by gazing at computer models of the economy and predicting GDP growth and inflation two decades out; it monitors key indicators, reviews its positions, and adjusts interest rates accordingly. It has succeeded remarkably well at keeping inflation in check even as parts of the economy—such as the mortgage lending sector—periodically blow up.

That approach contrasts with what's known as the precautionary principle—the doctrine that policy makers should base their decisions on avoiding the worst-case scenario. Precautionary models developed by economists including Martin Weitzman, of Harvard, dictate that even if the risks of climate catastrophe are small, its effects would be so radical that it should be avoided at almost any cost. The problem with such an approach is that it requires politicians to marshal tremendous resources and take aggressive actions—such as drastically limiting carbon emissions in poor countries like India—that may be unrealistic and even harmful.

The system Allen and Otto propose would respond directly to the amount of measurable warming attributable to human activity. The scheme has a straightforward prescription: the world must reduce emissions by 10 percent for every one-tenth of one degree of warming (beyond the 1 °C mark we have already effectively reached). As temperatures near 2 °C of warming, emissions ratchet progressively downward, eventually to near zero. The system responds to uncertain outcomes with a built-in self-adjusting mechanism.

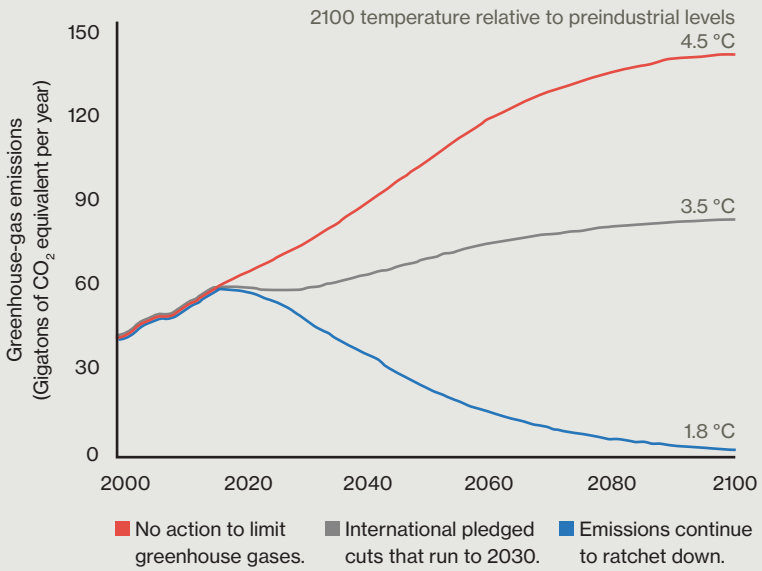
There are advantages to this system, and some pitfalls. Among the benefits is that it gives policy makers and governments political cover: whether the observed warming is less than or greater than predicted, the system responds automatically to the signals. The formula for those adjustments is agreed to in advance. "If you're waiting for science to provide exact certainty about regional local change over a multi-decade period, you're going to be waiting forever," says Diffenbaugh.

What the Allen-Otto system doesn't do is account for the uncertain effects of specific amounts of warming—it assumes nothing about sea-level rise, the frequency of extreme weather events, or other unpredictable effects of a warmer planet. "We are framing this system on the premise that the world has agreed to avoid more than 2° of warming, independent of the effects," says Allen. "It would be hard to go further than that in an international system, because you would need to get agreement on the degree of unacceptability of impacts."

The larger problem, of course, will be putting such a system in place. Getting politicians to commit to voluntary emissions limits decades in advance has taken many climate summits, over many years. Getting them to agree to a system that enforces bigger and bigger cuts based on a formula is a challenge of a different order. But as evidence for the consequences of climate change accumulates in unpredictable ways, this system may be the best way to make the cuts we need.

Richard Martin is MIT Technology Review*'s energy editor.*

THREE OUTCOMES BASED ON OUR ACTIONS



CLIMATE INTERACTIVE

The Energy Startup Conundrum

An inventor of a storage technology tries to outlast a brutal stretch for new energy companies.

Danielle Fong has a clever way to widen the use of renewable power: take the electricity produced by, say, a wind farm and use it to compress air in carbon-fiber tanks. When the wind quiets down, use the compressed air to drive an electric generator, eliminating the intermittency that consigns wind farms to a small role on the grid. The concept isn't new, but it has been limited because air heats up as it is compressed, making it difficult to store. Fong figured out that spraying water into the tank to cool the air makes it possible to store so much energy that it could be cheaper than using batteries. In 2009, she cofounded a company called LightSail Energy that has raised $70 million from the likes of Bill Gates and Peter Thiel, but it still is only on the verge of key demonstration projects. Fong, 28, spoke to *MIT Technology Review*'s executive editor, Brian Bergstein, about the challenges of commercializing energy technologies.

You're planning to begin pilot tests in 2016. Why is it taking this long to scale up your technology from the lab?

We thought that we would be out in the market about twice as fast. We were going to cut some corners by converting an off-the-shelf natural-gas compressor. Ultimately, we decided that would be too much of a compromise. In early 2012 we decided to switch and just go directly to the product that we would ultimately want.

Part of it is there's a lot more to do than we expected. Part of it is it's difficult to find financing, although we have raised a decent amount.

Why hasn't the money you've raised been enough?

It's not actually a lot of money compared with how much it takes to develop an engine, for example, or a compressor. Say you're a power plant company, and you're trying to make a better gas turbine. Even when you hit volume, you're going to be spending more than $100 million, maybe a couple hundred million dollars. Who writes those checks? There just aren't that many. There used to be. Those times are over. Now what you need to do is figure out how to get to a commercial scale so that you can bring the unit cost down without spending that kind of money.

Our answer to that, by the way, is our tanks. We have the most advanced carbon-fiber tanks, we think, on the planet for bulk storage of gases. We're manufacturing and selling the tanks, with a healthy profit, [to] the natural-gas industry.

CERN

And yet you still need to raise more money.

Our plan has us going profitable on less than $30 million [of] additional capital. Technically, we wouldn't need to raise money after that, if all goes according to plan.

There were so many things when we started out that people said, "This is impossible. If you spray water into an air compressor, it'll break. Will it transfer heat fast enough? Can you separate the water from the air? Can you compress and expand out of the same system? Can you build all of this stuff?" We've done the impossible on, I think, a reasonable budget.

Does it frustrate you that in other tech sectors, money is very easy to come by?

I will admit a fair amount of frustration. There are a dozen venture-funded apps to pick up your dry cleaning.

If we fail here, and it may well be the right solution, no one is ever going to get funded to do it again.

It must seem both promising and daunting that the opportunity is so huge.

We need energy storage in the terawatts. We're talking about getting to half a megawatt [with each of LightSail's storage machines]. That's a factor of a million. That's where my head is at.

Kindergarten for Computers

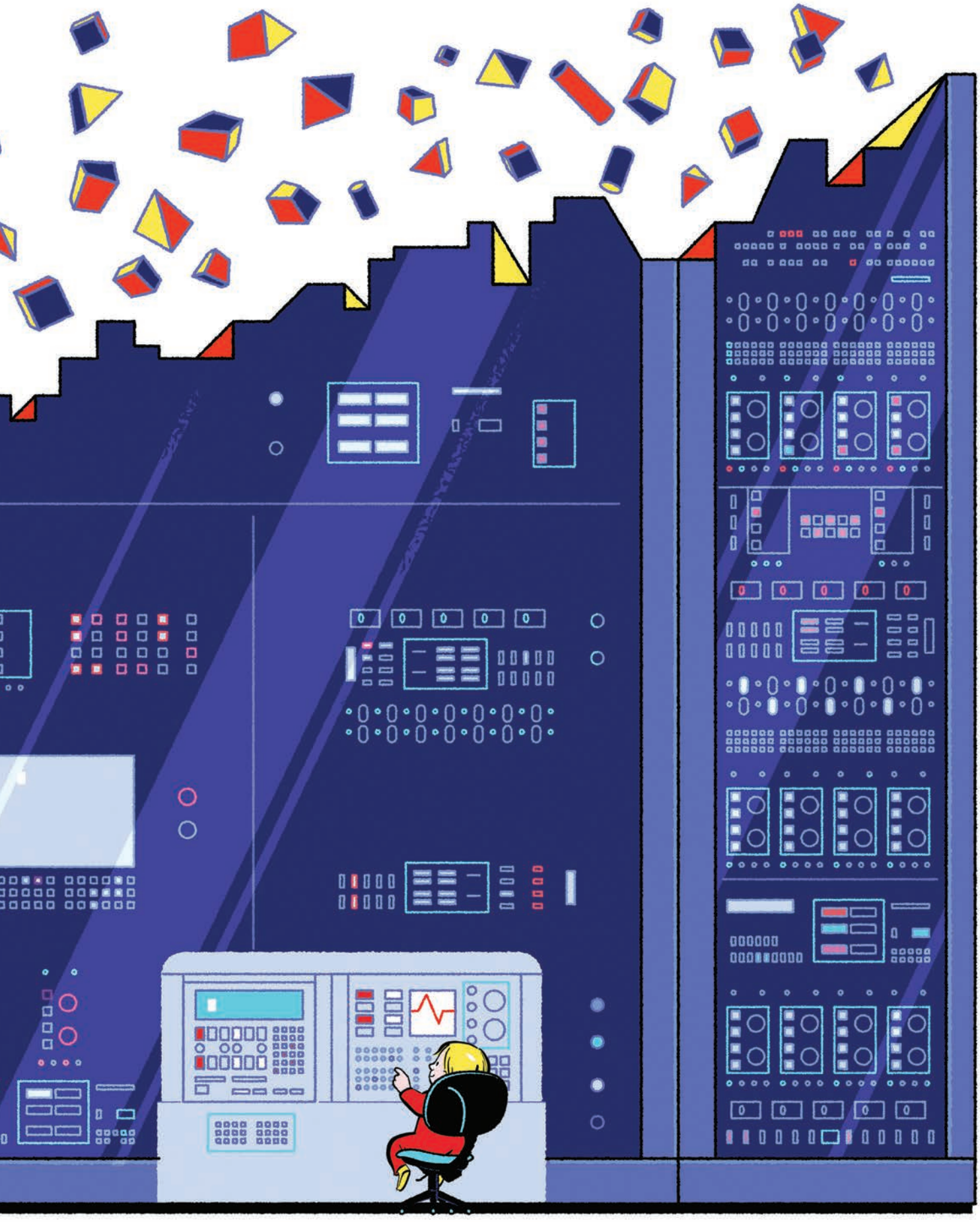
One cognitive scientist thinks the leading approach to machine learning can be improved by ideas gleaned from studying children.

By Will Knight

Like any proud father, Gary Marcus is only too happy to talk about the latest achievements of his two-year-old son. More unusually, he believes that the way his toddler learns and reasons may hold the key to making machines much more intelligent.

Sitting in the boardroom of a bustling Manhattan startup incubator, Marcus, a 45-year-old professor of psychology at New York University and the founder of a new company called Geometric Intelligence, describes an example of his boy's ingenuity. From the backseat of the car, his son had seen a sign showing the number 11, and because he knew that other double-digit numbers had names like "thirty-three" and "seventy-seven," he asked his father if the number on the sign was "onety-one."

NISHANT CHOKSI



"He had inferred that there is a rule about how you put your numbers together," Marcus explains with a smile. "Now, he had overgeneralized it, and he made a mistake, but it was a very sophisticated mistake."

Marcus has a very different perspective from many of the computer scientists and mathematicians now at the forefront of artificial intelligence. He has spent decades studying the way the human mind works and how children learn new skills such as language and musicality. This has led him to believe that if researchers want to create truly sophisticated artificial intelligence—something that readily learns about the world—they must take cues from the way toddlers pick up new concepts and generalize. And that's one of the big inspirations for his new company, which he's running while on a year's leave from NYU. With its radical approach to machine learning, Geometric Intelligence aims to create algorithms for use in an AI that can learn in new and better ways.

Nowadays almost everyone else trying to commercialize AI, from Google to Baidu, is focused on algorithms that roughly model the way neurons and synapses in the brain change as they are exposed to new information and experiences. This approach, known as deep learning, has produced some astonishing results in recent years, especially as more data and more powerful computer hardware have allowed the underlying calculations to grow in scale. Deep-learning methods have matched—or even surpassed—human accuracy in recognizing faces in images or identifying spoken words in audio recordings. Google, Facebook, and other big companies are applying the approach to just about any task in which it is useful to spot a pattern in huge amounts of data, such as refining search results or teaching computers how to hold a conversation (see "Teaching Machines to Understand Us," September/October 2015).

But is deep learning based on a model of the brain that is too simple? Geometric Intelligence—indeed, Marcus himself—is betting that computer scientists are missing a huge opportunity by ignoring many subtleties in the way the human mind works. In his writing, public appearances, and comments to the press, Marcus can be a harsh critic of the enthusiasm for deep learning. But despite his occasionally abrasive approach, he does offer a valuable counterperspective. Among other things, he points out that these systems need to be fed many thousands of examples in order to learn

Is deep learning based on a model that's too simple? Marcus thinks computer scientists are missing a huge opportunity by ignoring many subtleties of the human mind.

AI Pioneers

Key figures in the history of artificial intelligence.

Donald Hebb (1904–1985)
Developed a theory explaining how networks of neurons in the brain enable learning.

John McCarthy (1927–2011)
Helped found the discipline of artificial intelligence; championed the use of mathematical logic in AI.

Allen Newell (1927–1992) and **Herbert Simon** (1916–2001)
Created the Logic Theorist, a program designed to mimic the logic skills of a human being.

Frank Rosenblatt (1928–1971)
Created an electronic device called the Perceptron that simulated simple neural learning.

something. Researchers who are trying to develop machines capable of conversing naturally with people are doing it by giving their systems countless transcripts of previous conversations. This might well produce something capable of simple conversation, but cognitive science suggests it is not how the human mind acquires language.

In contrast, a two-year-old's ability to learn by extrapolating and generalizing—albeit imperfectly—is far more sophisticated. Clearly the brain is capable of more than just recognizing patterns in large amounts of data: it has a way to acquire deeper abstractions from relatively little data. Giving machines even a basic ability to learn such abstractions quickly would be an important achievement. A self-driving car might not need to travel millions of miles in order to learn how to cope with new road conditions. Or a robot could identify and fetch a bottle of pills it has been shown only once or twice. In other words, these machines would think and act a bit more the way we do.

With slightly unkempt hair and a couple of days of stubble, Marcus seems well suited to his new role as an entrepreneur. In his company's space, a handful of programmers work away at expensive computer workstations running powerful graphics processors. At one point, when Marcus wants to illustrate a point about how the brain works, he reaches for what he thinks is a whiteboard marker. It turns out to be a misplaced dart from a Nerf gun.

Marcus talks rapidly when excited, and he has a quick sense of humor and a mischievous grin. He refuses to explain exactly what products and applications his company is working on, for fear that a big company like Google might gain an advantage by learning the crucial insights behind it. But he says it has developed algorithms that can learn from relatively small amounts of data and can even extrapolate and generalize, in a crude way, from the information they are fed. Marcus says that his team has tested these algorithms using tasks at which deep-learning approaches excel, and they have proved significantly better in several cases. "We know something about what the properties of the brain should be," he explains. "And we're trying, in some sense, to reverse-engineer from those properties."

Boy wonder

Marcus, who was born in Baltimore, became fascinated by the mind in high school after reading *The Mind's I*, a collection of essays on consciousness edited by the cognitive scientist Douglas Hofstadter and the philosopher Daniel Dennett, as well as Hofstadter's metaphorical book on minds and machines, *Gödel, Escher, Bach*. Around the same time, he wrote a computer program designed to translate Latin into English. The difficulty of the task made him realize that re-creating intelligence in machines would surely require a much greater understanding of the phenomena at work inside the human mind.

Marcus's Latin-to-English program wasn't particularly practical, but it helped convince Hampshire College to let him embark on an undergraduate degree a couple of years early. Students at the small liberal-arts school in Amherst, Massachusetts, are encouraged to design their own degree programs. Marcus devoted himself to studying the puzzle of human cognition.

Marvin Minsky
(born 1927)
Developed one of the first artificial neural networks, but became a proponent of the symbolic approach to AI.

David Rumelhart
(1942–2011)
Developed simulations showing how neural processing could enable perception, and devised much more sophisticated neural networks.

James McClelland
(born 1948)
Founded the connectionist movement with Rumelhart, and cowrote the seminal work *Parallel Distributed Processing*.

Geoffrey Hinton
(born 1947)
Developed techniques that allowed many more layers to be used in neural networks, creating the foundation for deep learning.

Steven Pinker
(born 1954)
Used research on children's acquisition of language to critique the connectionist interpretation of the human mind.

Gary Marcus

SAMANTHA CASOLARI

The mid-1980s were an interesting time for the field of AI. It was becoming split between those who sought to produce intelligent machines by copying the basic biology of the brain and those who aimed to mimic higher cognitive functions using conventional computers and software. Early work in AI was based on the latter approach, using programming languages built to handle logic and symbolic representation. Birds are the classic example. The fact that birds can fly could be encoded as one piece of knowledge. Then, if a computer were told that a starling was a bird, it would deduce that starlings must be able to fly. Several big projects were launched with the aim of encoding human knowledge in vast databases, in hopes that some sort of complex intelligence might eventually emerge.

But while some progress was made, the approach proved increasingly complex and unwieldy. Rules often have exceptions; not all birds can fly. And while penguins are entirely earthbound, a bird in a cage and one with a broken wing cannot fly for very different reasons. It proved impossibly complicated to encode all the exceptions to such rules. People seem to learn such exceptions quickly, but the computers balked. (Of course, exceptions, including "eleven" rather than "onety-one," can be confusing for humans too.)

Around the time Marcus was preparing to enter Hampshire College, a group of psychologists came up with an approach that threatened to turn artificial intelligence upside down. Back in the 1940s, Donald Hebb had presented a theory of how the nerves in the brain might learn to recognize an input. He showed how the repeated firing of neurons might strengthen their connections to each other, thereby increasing the likelihood that they would all fire again when fed the same input. Some researchers built computers with a similar design. But the abilities of these so-called neural networks were limited until 1986, when a group of researchers discovered ways to increase their learning power. These researchers also showed how neural networks could be used to do various things, from recognizing patterns in visual data to learning the past tense of English verbs. Train these networks on enough examples, and they form the connections needed to perform such tasks.

Calling their approach "connectionism," the researchers argued that sufficiently large neural networks could re-create intelligence. Although their ideas didn't take over immediately, they eventually led to today's era of deep learning.

Just as connectionism was taking off, Marcus was deciding where to do his graduate studies, and he attended a lecture by the renowned cognitive scientist Steven Pinker, then a professor at MIT. Pinker was talking about the way children learn and use verbs, and he was arguing, contrary to a pure connectionist perspective, that they do not seem to acquire the past tense of verbs purely by memorizing examples and generalizing to similar ones. Pinker showed evidence that children quickly detect rules of language and then generalize. He and others believe, essentially, that evolution has shaped the neural networks found in the human brain to provide the tools necessary for more sophisticated intelligence.

Marcus joined Pinker's lab at MIT at 19, and Pinker remembers him as a precocious student. "I assigned to him a project analyzing a simple yes-no hypothesis on a small data set of the recorded speech from three children," he said in an e-mail. "A few days later he had performed an exhaustive analysis on the speech of 25 children which tested a half-dozen hypotheses and became the basis for a major research monograph."

As a graduate student, Marcus gathered further evidence to support Pinker's ideas about learning and added insights of his own. He pioneered the computerized analysis of large quantities of cognitive research data, studying thousands of recordings of children's speech to find instances where they made errors like "breaked" and "goed" instead of "broke" and "went." This seemed to confirm that children grasp the rules of grammar and then apply them to new words, while learning the exceptions to these rules by rote.

A deep-learning system can be trained to recognize particular species of birds, but it would need millions of sample images and wouldn't know anything about why a bird isn't able to fly.

On the basis of this research, Marcus began questioning the connectionist belief that intelligence would essentially emerge from larger neural networks, and he started focusing on the limitations and quirks of deep learning. A deep-learning system could be trained to recognize particular species of birds in images or video clips, and to tell the difference between ones that can fly and ones that can't. But it would need to see millions of sample images in order to do this, and it wouldn't know anything about why a bird isn't able to fly.

Marcus's work with children, in fact, led him to an important conclusion. In a 2001 book called *The Algebraic Mind*, he argued that the developing human mind learns both from examples and by generating rules from what it has learned. In other words, the brain uses something like a deep-learning system for certain tasks, but it also stores and manipulates rules about how the world works so that it can draw useful conclusions from just a few experiences.

This doesn't exactly mean that Geometric Intelligence is trying to mimic the way things happen in the brain. "In an ideal world, we would know how kids do it," Marcus says. "We would know what brain circuits are involved, the computations they are doing. But the neuroscience remains a mystery." Rather, he hints that the company is using a grab bag of techniques, including ones "compatible" with deep learning, to try to re-create human learning.

> "If you want to get a robot to learn to walk, or an autonomous vehicle to learn to drive, you can't present it with a data set of a million examples of it falling over."

Common sense

The work at Geometric Intelligence is surely significant, because blending new ideas from cognitive science and neuroscience will undoubtedly be important for the future of artificial intelligence. Still, after meeting with Marcus, I felt a bit like a toddler trying to make sense of some unfamiliar digits. How will all this come together? I needed one of Marcus's collaborators to show me another piece in the puzzle of what the company is developing.

Zoubin Ghahramani, a professor of information engineering at the University of Cambridge in the U.K., is a cofounder of Geometric Intelligence. Ghahramani grew up in the Soviet Union and Iran before moving to Spain and the United States, and although he is precisely the same age as Marcus, he arrived at MIT a year later. But because the pair shared a birthday, they ended up throwing parties and socializing together.

Ghahramani is focused on using probability to make machines smarter. The mathematics behind that is complicated, but the reason is simple: probability provides a way to cope with uncertainty or incomplete information. Flightless birds may, once again, help illustrate this. A probability-based system can assign a high likelihood to the concept that a bird is capable of flight. Then, when it learns that an ostrich is a bird, it will assume that it can most probably fly. But other information, such as the fact that an adult ostrich usually weighs more than 200 pounds, could change this assumption, reducing the probability that an ostrich can fly to near zero. This flexible approach can imbue machines with something resembling a crude form of common sense, a quality that is fundamentally important to human intelligence.

Speaking via Skype from his office in Cambridge, England, Ghahramani suggests one particular application that he and Marcus have their eye on: training robots to handle complex environments. In robotics research, "having experiences is expensive," he says. "If you want to get a robot to learn to walk, or an autonomous vehicle to learn to drive, you can't present it with a data set of a million examples of it falling over and breaking or having accidents—that just doesn't work."

Given that probabilistic algorithms and other technology in the works at Geometric Intelligence would be compatible with deep learning, it is possible that eventually the likes of Google or Facebook will acquire the company and add it to its overall AI portfolio. And despite Marcus's criticism of connectionism and deep-learning fever, I have a hunch that he would be quite satisfied with such an outcome.

Even if that does happen, it will be significant if Marcus can show that the most miraculous learning system we know—the human mind—is key to the future of artificial intelligence. Marcus gives me another example of his son's cleverness. "My wife asked him, 'Which of your animal friends will come to school today?'" Marcus says. "And he says, 'Big Bunny, because Bear and Platypus are eating.' Then my wife goes back into his room and, sure enough, those toys are on a chair 'eating.'"

Marcus marvels that his two-year-old can reason about rules concerning human behavior—realizing that you're either going to school or doing something else—and construct a completely new sentence based on his growing understanding of the way language works. After a pause, and a smile, he adds: "Well, you show me the AI system that can do that."

Will Knight is MIT Technology Review*'s senior editor covering robotics and AI.*

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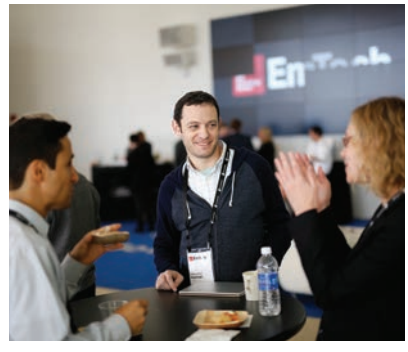

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CONTENTS

Funding Innovation

From Silicon Valley to Shanghai, investing in innovation is exploding. Investors, corporations, and governments look beyond unicorns to sustainably nurture big ideas.

MIGUEL PORLAN

The Big Question

At a Time of Plenty, Some Technologies Are Shut Out

New funding methods claim to democratize investment in innovation, but important technologies still struggle.

● Today there are more ways to fund a new company than ever—from crowdfunding platforms to early-stage angel investors, tech incubators that nurture ideas in management boot camps, wealthy family foundations, corporate venture funds, and record levels of venture capital.

On crowdfunding platforms, where entrepreneurs are now raising billions of dollars a year, the big winners are companies making some kind of object that consumers can envision buying and using themselves. Among venture capital investments, software is reaping the lion's share: $21.5 billion in 2014, or 42 percent of all dollars invested, compared with $6 billion for biotechnology and $2.4 billion for industrial and energy companies, according to data from an annual study by PricewaterhouseCoopers and the National Venture Capital Association.

This limited focus is driving up the valuation of certain kinds of companies and creating an investing bubble. But an even more important issue—the central question in this Business Report—is whether the mechanisms for funding innovation today can nourish a broad range of technologies: not just car-sharing services like Uber, but valuable technologies for making energy cleaner, reducing poverty, and improving health care.

"The best ideas don't always get financed," says Harvard Business School professor Ramana Nanda, an expert in entrepreneurship funding.

Among the areas suffering from insufficient investment, according to a recent report by a committee of MIT professors: medical research into Alzheimer's and infectious diseases, cybersecurity for non-defense systems, agricultural R&D that could help address the world's soaring need for food, and even areas of next-generation computing.

Capital-intensive industries are particularly ill-suited to today's methods of funding. For example, it can take years and hundreds of millions of dollars to determine whether innovations in large-scale energy production can work, because they require the construction of a factory or some other large facility. Though venture investors showed interest in energy startups for a brief period in the late 2000s, that window of opportunity has largely closed, leaving the companies scrambling to find new options.

When Aaron Fyke founded his company Energy Cache in 2009, it was a good time for green-energy startups. The company, which was developing a mechanical battery to inexpensively store energy generated by wind turbines and solar power, attracted early seed investing from the tech incubator Idealab and others, and it used that to build a prototype. But when Energy Cache went back several years later looking for $20 million to fund two more rounds of development before the product could get to market, it was hard to find investors interested in this type of energy technology.

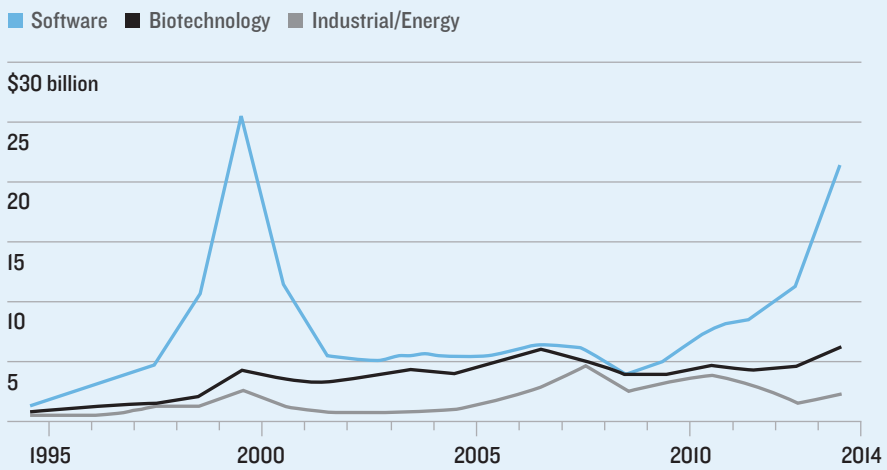
$47 billion
Value of venture fund investments made during the first nine months of 2015

Now raising money for a new company, Edisun, with a faster track to commercialization and a lower cost to develop its technology, Fyke says investors—including traditional venture capitalists, corporate VC arms, and wealthy individuals—have been much more enthusiastic.

Given the lack of big money, entrepreneurs like Fyke have had little choice but to refocus on low-capital technologies that use off-the-shelf components, but while that makes sense for them, it still leaves a question: how do we fund the high-capital technologies that we will also need?

For this group, funding has to be found beyond Silicon Valley venture capital firms—perhaps led by governments or by investors with a longer time horizon, like family foundations or corporate venture funds. GE Ventures, for instance, invests $200 million a year in startups in such fields as software, advanced manufacturing, energy, and health care. It has stakes in companies including Rethink Robotics and Airware, which makes drone software. "For the most part what we are

Software in the Sweet Spot
Once again, software benefits from a venture capital boom while other technologies lag.



SOURCE: PRICEWATERHOUSECOOPERS AND THE NATIONAL VENTURE CAPITAL ASSOCIATION

investing in, we hope to be customers of," says senior managing director Karen Kerr.

For medical-device makers—which, like energy companies, often draw little interest from VCs—crowdfunding has strategic advantages. Scanadu, the maker of a small device packed with sensors that can measure temperature, heart rate, blood pressure, and other bodily signals, has smartly use its fund-raising to prove market interest. By raising $1.6 million on Indiegogo, the company got 7,000 backers eager to test its prototypes. That provided valuable data to show regulators reviewing the device and helped persuade later-round venture capital funders that there is a market for Scanadu's products.

Now four years old, the company has $49.7 million in backing—including funds from two strategic Chinese backers, the Internet giant Tencent and the investment group Fosun, which has a large health business. It has begun thinking of rolling out in China after the U.S.

The dominance of venture capital in the innovation-funding environment is not just a U.S. phenomenon. China, once exclusively a bastion of government-funded research, is now the second-largest VC market, behind the United States. Companies in China collected 18 percent of global VC investment in 2014, or about $15.6 billion, compared with $4.8 billion the year before, according to data compiled by the global accounting firm EY. India's share has been climbing too, with $5.2 billion invested in 2014—more than double the 2013 total of $1.9 billion.

Yet in this increasingly global funding picture, certain innovations are still struggling: potential breakthroughs in energy production and medicine, among others, that take too much money and time to develop. A better financing system, says Harvard's Nanda, would support a sort of Darwinian evolution of technology. "Each new technology is like a mutation," he says. "Most will end up failing. A few will be an incredible success. We want to develop financial systems that will encourage experimentation and a high rate of new variations and then be quick at shutting down those that don't work."

—Nanette Byrnes

Innovation Hub

An Innovation Case Study: Pittsburgh

Can a midsize Rust Belt city compete with Silicon Valley?

● Shortly after Luis von Ahn helped launch Duolingo, his popular language-learning app, he started to receive the same piece of well-meaning advice from investors and fellow entrepreneurs: Why don't you move from Pittsburgh to Silicon Valley, where you can really grow?

Presumptuous? Sure. But not that surprising. The Bay Area is the center of the tech world, a siren for software developers, deep-pocketed investors, and enterprising businesspeople. Companies based in San Francisco and San Jose pulled in $22.6 billion in venture capital funding in 2014, dwarfing the cities' closest competitors, Boston ($4.4 billion) and New York ($4.2 billion). Pittsburgh firms scored a paltry $338 million.

Smaller tech cities do have a serious downside when it comes to the tech world: they often lack big-time venture capitalists and the pool of startup-savvy business and marketing talent that can help a small company grow.

Von Ahn and other startup CEOs, though, are beginning to push back against this argument.

They make the case that Pittsburgh and other second-tier tech cities—including Raleigh, St. Louis, and Minneapolis—are places with strong university pipelines, affordable living costs, great quality of life, and collaborative tech ecosystems. "Despite the fact that a lot of people have told us to leave," von Ahn says, "we're happy here."

Expanding the tech economy beyond the West and East Coasts could support inventors tackling problems that those based in the Bay Area might overlook. "The culture of Silicon Valley is really a bunch of twentysomethings solving twentysomethings' problems," says Matt Zieger, the vice president of the Forbes Funds in Pittsburgh, which has invested in local startups that fight human trafficking and provide voice-based apps for the visually impaired.

Pittsburgh "has a culture of a broader purpose," says Zieger. "We have a legacy of building things." Some of the hottest companies in the city today are working on complex technologies with real-world applications, including advanced robotics, low-cost batteries to store renewable energy, and self-driving cars.

Pittsburgh has not always evolved smoothly. Thirty years ago, it was a hollowed-out, crumbling Rust Belt city whose economic engine had seized with the meltdown of the American steel industry. As unemployment soared and home values plummeted, young people left to find jobs and lives elsewhere.

Today, that's history. Neighborhoods are undergoing building booms, industrial wastelands on the riverfronts have become bike trails and parks, and the city's percentage of educated 25- to 34-year-olds is among the highest in the country. While a strong manufacturing base remains, health care and technology have become the twin economic engines of the region. They're supported by the neighboring urban campuses of the University of Pittsburgh, which pulls in over $400 million in National Institutes of Health funding annually, and Carnegie Mellon University, which has top graduate programs in computer science, engineering, and robotics and tight connections

Thirty years ago, Pittsburgh was a hollowed-out, crumbling Rust Belt city whose economic engine had seized with the meltdown of the American steel industry.

to industry. Duolingo's von Ahn remains a CMU faculty member, as does Jay Whitacre, the founder of Aquion Energy, a battery company based on his invention. Andrew Moore—who ran Google's Pittsburgh office for eight years—recently returned to academia and is now the dean of CMU's computer science school.

Campus talent has been a draw for major companies, including Apple, Disney, Intel, and IBM. Google arrived in 2006 and now has 400 engineers on site.

This past February, Uber announced it was partnering with CMU to open a 53,000-square-foot research and development facility focused on designing self-driving cars. It also hired away more than 40 of Carnegie Mellon's researchers, prompting grumbles about the big tech companies swiping the best local talent. But most people are glad to have them here. "As you're recruiting executives to move here [for a startup job], Google provides a sense of stability," says Sean Ammirati, a partner at Birchmere Ventures, a local investment company. "If the startup doesn't work out, there is a place to transition to. And a lot of people who work at those big companies get bored pretty quick, so they look for something different to do."

The Pittsburgh sell to out-of-staters: despite being relatively small (the population hovers around 300,000), the city boasts top-notch sports, arts, culture, and outdoor attractions. Within driving distance of Philadelphia, Washington, and Baltimore, it is well positioned for companies needing to distribute physical products. Also, housing costs 10 times more in San Francisco than it does in Pittsburgh.

$426 million
Annual NIH funding for the University of Pittsburgh

One piece of evidence that Pittsburgh's profile is rising in the tech community comes from Silicon Valley: more than 100 national venture funds have invested in Pittsburgh companies in the past five years.

There are cons to a smaller tech city, too. Finding nontechnical talent—from lawyers to salespeople to marketing staff—remains a challenge, and even securing a flexible workspace from landlords can be tough. "We have 55 employees right now, and next year we will have 155," says Duolingo's von Ahn. "It's impossible to convince someone here to sign a lease that makes sense for a startup. We cannot sign a lease for 10 years—by then, we will either disappear or we will be 10 times larger!"

Getting direct flights to San Francisco to woo investors or talent can be tough; for three months in 2015, there were actually *no* direct flights from Pittsburgh to the Bay Area. There are also few tech employers here with the HR and legal know-how to secure H1B visas for international employees.

And the region's affordability, in many ways a virtue, can also cut the other way. "The sense of urgency here is not as apparent as it is in the Bay Area," says Phil Marzolf, a Silicon Valley veteran who now works as a Pittsburgh-based advisor to startups. "When somebody has an idea in California, you have to run nonstop. Here, too many people get complacent."

The largest challenge, though, is the lack of big-time investors. Duolingo raised all its money outside the region, while other companies that started in Pittsburgh, like Anki (a robotics company) and BlackLocus (a business software startup), have followed investments out of state. The founders of Modcloth, a clothing retailer that started out selling vintage styles online, found that while Pittsburgh was a great place to bootstrap their company and find affordable warehouse space, they eventually outgrew it. When they raised their second round of venture capital, they moved their headquarters to California to tap into their investor networks in the Bay Area.

"Pittsburgh is a great place to have a startup," says cofounder Susan Gregg Koger, "but it's not a great place to keep scaling yet."

"What we really need is for someone to become an icon," says Dave Mawhinney, the co-director of CMU's Center for Innovation and Entrepreneurship. "Harvard has Facebook, Stanford has Google, and Carnegie Mellon has ... fill-in-the blank." Without that, Pittsburgh lacks the abundance of tech wealth that gets reinvested in new startups so regularly in Silicon Valley. Observers say there are a handful of local companies that have the potential to get there (see sidebar), but they are all still a few years away from the point where a public offering might make sense.

Local entrepreneurs, though, say that a large IPO is only a matter of time. "When that happens," says von Ahn, whose company is on the short list, "that's when we're going to see a big change."

—Patrick Doyle

Pittsburgh's Great IPO Hopes

Despite a strong startup scene, the city still lacks a home-grown tech icon. Here are the companies experts say have the best shot at a big IPO in the next few years.

	Founded/ University Tie	Leader(s)	Product
4MOMS	2006 / n/a	Rob Daley, Henry Thorne	High-end robotics products for child care
AQUION ENERGY	2008 / CMU	Jay Whitacre	Low-cost batteries
DUOLINGO	2011 / CMU	Luis von Ahn, Severin Hacker	Language-learning application
NOWAIT	2010 / CMU	Robb Myer, Ware Sykes	Restaurant-management software

Expert Q&A

VC Bill Gurley Tries to Bust the Bubble

A prominent Silicon Valley venture capitalist argues that tech startups are overvalued, profits are underrated, and a bust is coming.

● Since last year, Bill Gurley—a partner at the venture capital firm Benchmark, known for early investments in Uber, OpenTable, and Zillow—has stood out from his VC counterparts for his insistence that there's a bubble in tech startup valuations. In particular, he says "unicorns"—startups valued at $1 billion or more—are the most visible sign of an explosion in valuations that he thinks will end in a bust just as surely as previous bubbles did.

Nonetheless, Gurley told contributing editor Robert Hof he remains optimistic that entrepreneurs will keep innovating even in a downturn. He highlighted innovations in his own field, such as Internet-driven crowdfunding and early-stage startup incubators, that are opening entrepreneurship to more people.

You've complained for more than a year that we're in a tech-startup investment bubble. Why does that concern you so much?
Great entrepreneurs are relatively disadvantaged in these markets where so much capital is available. In a market where capital is hard to come by, they can still raise money. In this market, they can raise a ton of money, but so can a lot of [less capable] competitors that wouldn't be in business otherwise.

Many investors say seemingly excessive valuations of startups are actually justified because they have real revenues and growth prospects.
Imagine two companies. One is told, "I want you to get to $100 million in revenue and you have to be profitable when you get there." The other is told, "I want you to get to $100 million in revenue and I don't care if you lose $40 million getting there." Which of those two exercises is harder, and by how much? I would argue it's at least 10 times harder to do the first.

Until you can prove that you can generate cash flow, you don't have a sustainable business. No matter which of these unicorn boardrooms you walk into, everybody thinks it's perfectly okay to burn tons of money.

Amazon was losing lots of money years ago but managed to create a huge, sustainable business.
Look what they had to go through. The stock went from $106 [in December 1999] to $6 [in October 2001], a 94 percent reduction in market value. They had

to lay off 1,300 people, 15 percent of the head count. I don't think there's a single unicorn out there that's thought in their mind, "Wow, what if my market cap goes down by 94 percent?"

But if you don't join the race, you can't win it, right?
Once your competitor raises $400 million, you don't get to choose whether you're in that game or not. But I've lived through crashes and it sucks. When these markets correct, they correct hard. There's no soft landing in Silicon Valley.

Despite your warnings, startups continue to get big funding. Do you wonder if you're still right?
No. There have been some signs very recently of a shift in the winds. You've got the stock market down dramatically for the year. You've got contraction of multiples [valuations that are a smaller multiple of annual sales than they were a few months ago] in most of the tech startups. I've seen venture companies that normally would keep all the deals for themselves start soliciting other people's money to help fill up new rounds.

Would a bust cool spending on innovation?
Good companies are started in all parts of the cycle. Capital is cyclical, but I don't think innovation has ever not happened in Silicon Valley.

How has venture capital changed in the face of alternatives such as incubators, super-angel investors that put small amounts of money into early-stage startups, and crowdfunding?
Six or seven years ago all of our limited partners got scared because there was this notion that the super-angel was going to get rid of the venture capitalist. It didn't play out that way. Only a handful have proven themselves.

If you're an inventor, the crowdfunding thing is cool because you probably couldn't have gotten an [initial round of venture capital] and you might succeed [with crowdfunding]. I think that's great. Y Combinator is also an innovation. Venture is a business that is not really prone to systemization. [Benchmark cofounder] Bob Kagle used to call it a shoe-leather business. So anyone who builds a new type of system is interesting. But we do have a fundamental belief that company building is an art, not a science.

Where would you like to see more investment?
Health care. The tools like the smartphone that have disrupted other industries should be so useful in solving the health-care problem. But most of the startups we find have basically discovered some opportunity to help one of the incumbents maximize their value extraction in the system. They use the technology to make the system worse as a whole rather than better.

ROBERT RISKO

Case Studies: Magic Leap, Megascale Desalination, Liquid Biopsies

Bankrolling Breakthroughs

Every year, *MIT Technology Review* selects 10 breakthrough technologies, innovations that we believe will have lasting impact. Just as each technology has taken a different path to development, each has its own funding story. Here are the tales of three of those breakthroughs from 2015: the augmented-reality technology of Magic Leap, megascale desalination, and liquid biopsies.

Virtual Reality, Real Cash

Magic Leap had no trouble raising money from a cache of A-list investors enthusiastic about the changing economics of virtual reality.

● In 2014, when Rony Abovitz was talking to venture capitalists and corporate backers about his latest technology company, Magic Leap, he should have had a hard sell. For starters, he had to convince them that a new idea, combining real life with augmented reality into what he calls mixed reality, could not only work but become the basis for a whole new industry.

What Magic Leap is doing is complicated, and different from other virtual-reality technologies like those behind Oculus Rift and Samsung's Gear VR. *MIT Technology Review* senior editor Rachel Metz, who has tested a prototype, describes it as "a tiny projector that shines light onto a transparent lens, which deflects the light onto the retina." That light then blends in with the light being seen in the real world, leaving artificial objects "nearly indistinguishable from actual objects."

Though Abovitz had a lot to explain, it didn't turn out to be a difficult pitch to make. In two rounds, one in February 2014 and the other in October 2014, Magic Leap raised $592 million from backers including Google and Qualcomm Ventures, Wall Street financiers KKR and Vulcan Capital, and Silicon Valley VC firms Kleiner Perkins Caufield & Byers and Andreessen Horowitz. (An October report said that the company was seeking an additional $1 billion in backing.)

That money is going into hiring engineers and other experts—Magic Leap's employees now number in the hundreds—and setting up a 260,000-square-foot pilot manufacturing facility in Florida. Abovitz says Magic Leap needed all that money "to really go to the moon" and develop brand-new technology.

Abovitz founded Magic Leap in 2010, and it became his full-time gig in December 2013 after he sold his previous business, the medical-device maker MAKO Surgical, for $1.65 billion. Nagraj Kashyap, senior vice president at Qualcomm Ventures, attributes much of his firm's enthusiasm for Magic Leap to Abovitz's track record building successful technologies and cultures. But he also sees good reason to believe that Magic Leap's technology will create something new, a "pervasive and persistent" form of augmented reality.

In two financing rounds, Magic Leap raised more than half a billion dollars, money now going into hiring hundreds of staffers and setting up a new manufacturing line in Florida.

Although virtual reality is not new, investors have been drawn back to it because of a substantial decrease in costs. Virtual-reality headsets that existed 20 years ago cost $20,000 to make, says Philip Rosedale, creator of Second Life and High Fidelity. Because it was so expensive, he says, "virtual reality in general has been a dream always five years in the future."

In contrast, today "90 percent of the hardware in a virtual-reality headset is already in a cell phone," says Nabeel Hyatt, a partner at Spark Capital, the original backer of Oculus VR, the virtual-reality headset maker Facebook bought in 2014 for $2 billion.

$592 million
Amount Magic Leap raised in 2014 from private investors

Spark Capital professes to like investing in markets so new their size can't yet be determined. Even so, Hyatt says his firm believes the augmented reality of Magic Leap is still too far off to warrant investment. Significant technological puzzles still have to be solved in computer vision, 3-D rendering, strategies for mapping a room in real time, and other areas, Hyatt argues. "I am bullish on that," he says, "but over the very long term."

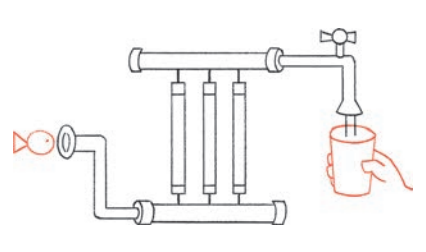
—Nanette Byrnes

Funding Desalination

The world's biggest desalination plant, named one of *MIT Technology Review*'s breakthroughs of 2015, is the result of government funding of both large-scale infrastructure and the underlying innovations.

● The world's largest seawater desalination plant, now operating on the Israeli coast, is a study in government financing of innovative technologies over the course

LAURENT CILLUFFO



The structure of the financing is meant to keep the plant operating in top condition for decades, producing inexpensive water for a dry land.

of more than half a century, starting with the funding of basic research and ending with a public-private partnership to build a vast new facility.

The project was ordered by the state of Israel, its construction financed with $500 million in bank loans issued to a private consortium. Revenue from freshwater sales to the state will both repay those loans and provide built-in profits for the consortium.

The underlying technologies at work in the project are also the result of government support, though in this case it was government-funded academic research on desalination membrane materials that was centered in California in the 1950s and 1960s.

$500 million
Amount in bank loans used to build the Sorek facility

The plant, 10 miles south of Tel Aviv, is called Sorek Desalination. In operation since late 2013, it now provides 20 percent of the water consumed by Israeli households, or 150 million cubic meters per year.

To finance an operation that big, a consortium led by a private company, IDE Technologies, promised to sell the water to the state at 58.5 cents per cubic meter of output—a price that can fluctuate with energy costs and local inflation. That's one of the lowest prices ever for such a plant.

About 20 percent of the cost was borne by the consortium, with the rest coming from low-cost loans made by two Israeli banks and the European Investment Bank, an arm of the European Union. After their initial investment is recouped from sales over the plant's first few years of operation, the consortium will earn profits on the investment, a structure meant to keep the plant operating optimally for decades. After 25 years, the sprawling facility will be owned by the state of Israel.

At the heart of the Sorek plant are polymer membranes inside tubes. When seawater is passed through the tubes and placed under pressure, fresh water is forced through the membranes, and saltier water is held back. Development of the membranes was funded by U.S. and California agencies starting in the early 1950s, a time of significant population growth and concerns over the supply of fresh water. The U.S. Department of the Interior created the Office of Saline Water in 1952 to fund desalination research projects; California's government did the same, establishing research labs at state universities.

In the early 1960s, private companies largely took over the work; Dow Chemical and DuPont, among others, began R&D projects in desalination. From there, decades of incremental advances in materials and system designs made such plants more and more economical, culminating in Sorek and its low-priced water, which happens to use one of Dow's membranes.

Without government funding of the early fundamental materials research, the technical challenges of effective desalination might never have been solved. The public-private financing structure of the Sorek project underscores how government support continues to be essential in scaling up this technology so that water can flow to millions of Israelis at a reasonable price. *—David Talbot*

Funding Liquid Biopsies

Bankrolled by private investors and governments, cancer tests of blood and urine are coming to market.

● How much does it cost to bring to market a diagnostic test that's able to measure cancer without a tissue biopsy?

In the case of Trovagene, almost $100 million.

That's the cumulative loss, or expense including salaries, R&D, and office space, the money-losing San Diego biotechnology outfit has run up since 1999, when it set out to test for cancer from a cup of urine. Just like recently developed cancer blood tests, the diagnostic the company started offering in May searches for telltale scraps of tumor DNA released by dying cancer cells. The amount of tumor DNA that ends up in urine is a readout, the company says, of whether a tumor has been destroyed or is still growing.

Wall Street analysts expect demand for liquid biopsies to rocket toward $20 billion a year within five years, from about $100 million today.

The idea of such liquid biopsies has leapt to prominence in just the last year. Cancer researchers now expect that the tests will offer a noninvasive way to monitor cancer, find the genetic mutations driving a tumor, or even diagnose it early, before symptoms start. It's an innovation so big that Wall Street analysts at JP Morgan expect demand for liquid biopsies to rocket toward $20 billion a year within five years, from about $100 million today.

The first DNA blood test for cancer in the United States was commercialized in 2014 by Guardant Health, a venture-backed California company, and tests to spot cancer DNA in blood, urine, or spinal fluid are now in development by a growing number of companies but remain a risky bet for investors.

One pioneering researcher, Dennis Lo, is now tracking more than 20,000 people in Hong Kong to see whether blood screening can catch liver cancer early. Some of his early and ongoing work was paid for by a $1 million grant from the Kadoorie Charitable Foundation, the charity of Hong Kong billionaire Michael Kadoorie, and he later won a $4.25 million award from the Hong Kong government. "It took us about 10 years to convince people to fund us," he says. Lo says he recently cofounded a company called Cirina to develop blood tests, and he expects initial financing of $12 million from investors.

Investors in the new tests could be disappointed, because while developing a new diagnostic can cost as much as creating a new drug, it's notoriously hard to make any money off diagnostic tests. Consider Foundation Medicine, a company based in Cambridge, Massachusetts, that started testing the DNA of tumor tissue samples in 2011 but is now racing to launch a liquid biopsy using blood. The company has deep-pocketed venture backers including Google Ventures, but it has spent $192 million developing its tests and continues to lose millions of dollars every quarter.

It's still unclear how the U.S. Food and Drug Administration plans to treat this new group of tests. Another challenge: insurance reimbursement can be uncertain. And patents that once protected such investments and kept competitors away are being overturned.

In 2013, the U.S. Supreme Court said genes aren't patentable. Since then, other courts have extended the reasoning to liquid biopsies. The presence of cancer DNA in the body's fluids, they say, is also a "phenomenon of nature" and can't be patented either, even if you discovered it.

—Antonio Regalado

Innovation Funding

China's Latest Growth Market: Venture Capital

China's first-generation Internet entrepreneurs are now venture investors in the next generation, placing big, sometimes risky bets on early-stage startups.

● In 1999, when China's per capita income was just $850 a year, a 31-year-old entrepreneur named Neil Shen and three friends nevertheless bet that China would soon develop a huge domestic tourism industry. They created a travel-booking website, Ctrip.com. China's per capita GDP has since grown ninefold, and the domestic tourism market has ballooned to more than $400 billion. Ctrip, which had an initial public offering on Nasdaq in 2003 (and nearly doubled its price on the first day of trading), now has a market capitalization of over $10 billion—and Shen, who went on to found other travel-related companies in China, is a billionaire.

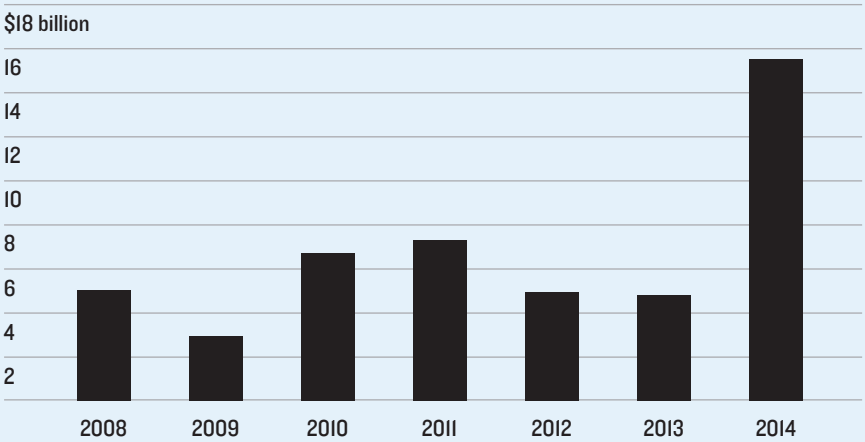
In 2005, Shen began to shift roles, from star entrepreneur to venture investor. Much like U.S. counterparts such as Netscape founder Marc Andreessen at Andreessen Horowitz or Paypal cofounder Peter Thiel at Founders Fund, Shen has made the next chapter in his career about discovering and nurturing a new generation of entrepreneurs.

He founded the independently run China affiliate of venture capital titan Sequoia Capital and now manages a portfolio that is worth, according to the *Financial Times*, roughly $6 billion. The range of Sequoia Capital China's investments testifies to the energy and diversity of China's burgeoning startup scene—from e-commerce platforms like luxury-bargain site Vipshop to science-oriented companies, including DeepGlint, which specializes in computerized 3-D image analysis; Magi, a search engine made by Peak Labs that gives answers instead of references; and drone maker DJI.

In becoming a venture capitalist, Shen was once again ahead of the curve in China. According to data from the World Economic Forum, Chinese venture capital, which had consistently accounted for roughly 9 percent of the global total from 2006 to 2013, spiked to 18 percent (about $15.6 billion) last year. PricewaterhouseCoopers recorded 1,334 venture capital deals in China in 2014, up from 738 in 2013 and 473 in 2012. Last year, China eclipsed Europe to become the second-largest destination for venture capital, after the U.S., according to the WEF.

A Funding Gold Mine

In 2014, 18 percent of global venture investing happened in China.



SOURCE: EY

Key Venture Capital Players

The burgeoning Chinese venture capital scene includes company founders and professional financiers.

NEIL SHEN	Founding and managing partner, Sequoia Capital China. Major investments include antivirus software maker Qihoo 360 and discount retailer Vipshop.
FENG TAO	Founder and CEO, NewMargin Ventures. Major investments include mobile ad firm Panshi and Internet apparel retailer Vancl.
KATHY XU	Founder, Capital Today. Major investment is BeiBei, a site selling baby products.
SUYANG ZHANG	General partner, IDG Capital Partners. Major investments include the picture and video app Meitu and Royole, which makes displays for smartphones and other devices.
XU XIAOPING	Founder, ZhenFund. Major angel and VC investor funding the Minerva Project, an ed-tech firm, and Nice, which allows you to embellish photos on social-media networks.

This boom is supporting a new kind of startup investment in China—earlier-stage and riskier. The number of investors has grown, but so too has their sophistication, says Jeongmin Seong, a senior fellow at the McKinsey Global Institute in Shanghai. In 2009, early-stage investment in China accounted for 16 percent of total venture capital and angel investment, says Seong. By 2014, it had nearly doubled, to 31 percent. Investors are putting more money into early-stage deals because the competition for safer investment opportunities has become fierce. "The risk-to-reward calculation is changing," says Rui Ma, a 500 Startups venture partner who splits her time among Beijing, Shanghai, and Silicon Valley.

Venture capital began to be available in China 10 to 15 years ago, when overseas funds started opening offices in the country to scout investment possibilities. Until then, options for would-be entrepreneurs were limited: many founders used their own savings, or pooled money from relatives living both inside and outside mainland China. Historically, China's state-owned banks have strongly favored lending to state-owned companies, because of a widely held assumption that the government would step in to save even failing ones. That's still true today.

Zennon Kapron, founder of the financial industry research firm Kapronasia in Shanghai, attributes the rise in venture capital to the class of Chinese entrepreneurs who have grown wealthy from their own companies' public offerings. These business founders offer more than money to the startups they fund, says Kapron: "The knowledge, network, and experience that a Neil Shen can bring to the table as well is very powerful. Chinese business is still very much driven through relationships, and having that in place can be critical for any startup."

Other Chinese tech giants that have gone public in the past decade—Baidu (2005), Alibaba (2014), and Tencent (2015)—had founders who, like Shen, went on to manage VC firms. Often called the "first generation" of China's Internet titans, they include Alibaba's Jack Ma, who founded Yunfeng Capital; Xiaomi's founder Lei Jun, who launched Shunwei Capital Partners; and Pony Ma, who has overseen Tencent's transformation into an investing powerhouse in its own right.

Their impact extends beyond their direct VC investments, inspiring the swelling ranks of both entrepreneurs and investors in China by legitimizing the startup dream. "Before, there was a huge pressure for young people to graduate college and immediately go work for a stable established company and begin to send money back home," says William Bao Bean, a Shanghai-based partner at venture capital firm SOSV and managing director of Chinaccelerator. "Today the kids who want to launch startups can tell their parents they have role models." In a survey of graduates from Peking University, one of China's top colleges, only 4 percent identified as entrepreneurs or self-employed in 2005; by 2013, the proportion had grown to 12 percent.

Bob Zheng grew up in Shanghai and then went to college in Canada, where he stayed to work for consultancies for eight years. In 2008, he came back to Shanghai to launch an online education startup. At that time, it was "still a bit early for VC," he recalls, and the initial funding came from his cofounder's own savings. When his team sold the company in 2010, he plowed his earnings into a new business model that wouldn't have been possible even a few years before: launching and managing co-working spaces for other entrepreneurs, called People Squared. Today, Zheng's team runs 15 co-working spaces in Shanghai and Beijing, hosting about 250 startups, most of them tech-focused. He plans to open spaces in Hangzhou, Nanjing, and Shenzhen soon.

China's great size is both a blessing and curse for startups: there's opportunity to scale up quickly, but also plenty of competition. "In the U.S., if someone has an idea, maybe three other startups are working on the same idea," says Rui Ma of 500 Startups. "In China, maybe 10 or 20 funded companies or more are competing on the same idea."

—Christina Larson

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Reviews

Hot and Violent

Researchers have begun to understand the economic and social damage caused by climate change.

By David Rotman

No one knows how climate change will transform our lives. Not only is it uncertain how much elevated levels of carbon dioxide in the atmosphere will raise temperatures and affect precipitation in different parts of the world, but there remains much to learn about how these changes will reduce agricultural productivity, damage human health, and affect economic growth. In addition to these worrisome unknowns is a question that provokes even deeper anxiety: could the damage wrought by climate change, or even the threat of it, lead to a far more violent world?

In *Black Earth: The Holocaust as History and Warning*, Timothy Snyder argues that such fears have historical justification. A Yale University professor and a prominent scholar of the Holocaust, Snyder describes Hitler as driven by a twisted ecological panic that the German people would not have enough land to grow the food they needed. To Hitler, he writes, "ecology was scarcity, and existence meant a struggle for land." Hitler particularly lusted after the fertile lands of Ukraine. In fact, Germany was not in danger of starving, and Snyder points out that many of the agricultural improvements that would later produce the Green Revolution were already under way. But Hitler, Snyder explains, did not believe technology was capable of significantly increasing agricultural output; indeed, he rejected the idea that science in general could disrupt the racial struggle for survival he perceived.

Much of *Black Earth* is a description of how Germany ruthlessly destroyed neighboring countries and their political institutions, leading to the subsequent mass murder of Jews in those regions. But then, in the conclusion, Snyder makes a disturbing "warning" based on the lessons of the Holocaust. As the benefits of the Green Revolution peter out and the risks of climate change increase, he suggests, we are once again becoming vulnerable to fears of food insecurity—and, thus, once again in danger of battling over agricultural lands. "Another moment of choice, a bit like the one Germany faced in the 1930s, could be on the way," Snyder writes. He adds: "We have changed less than we think."

Snyder argues that the changing climate has already played a role in conflicts in Africa, such as the civil war in Sudan that began in 2003. But his real fears are for the future. China, he points out, is unable to feed itself with domestic agricultural production, and many of its people have personally faced the terror of starvation: the famine caused by Mao's Great Leap Forward between 1958 and 1962 killed tens of millions. Much as Germany in the 1930s envied the agricultural resources of Eastern Europe, China is increasingly attempting to control those of Africa and eyeing the vast resources of its neighbor Russia, says Snyder.

Invoking the haunting evils of Nazi Germany to warn of future dangers ignores the unique perversion of Hitler's thinking. And, as Snyder readily acknowledges, China is not Nazi Germany; its rul-

Black Earth: The Holocaust as History and Warning
By Timothy Snyder
Tim Duggan Books, 2015

"Climate change in the Fertile Crescent and implications of the recent Syrian drought"
By Colin P. Kelley et al.
PNAS, vol. 112, 3241–3246

"Global non-linear effect of temperature on economic production"
By Marshall Burke, Solomon M. Hsiang, and Edward Miguel
Nature, vol. 527, 235–239

JAVIER JAEN

ers have embraced science and technology in addressing climate change. Nevertheless, Snyder's fundamental point remains: climate change—even the prospect of it—has the power to grotesquely transform global politics. And if history is any guide, governments and rulers may not respond to the threats in a rational manner.

Syria and the Mideast

The suspicion that climate change will contribute to conflict is not new. Nicholas Stern, a former chief economist of the World Bank and advisor to the British government, predicted in his 2006 report "Economics of Climate Change" that "higher temperatures will increase the chance of triggering abrupt and large-scale changes that lead to regional disruption, migration and conflict." Over the last decade, many researchers have tried to document the connection.

In 2011, Solomon Hsiang, then at Princeton and now a professor at the Goldman School of Public Policy at the University of California, Berkeley, coauthored a paper showing that instances of civil war doubled in the tropics during times when the El Niño effect produced unusually warm temperatures at those latitudes. The paper was the first to demonstrate that a global climate effect could be linked to conflict. A few years later, Hsiang and his colleagues at Berkeley and Stanford analyzed the growing literature on climate and conflict and found a consistent result in 60 research papers: rising temperatures and changes in precipitation patterns increased the risk of conflicts.

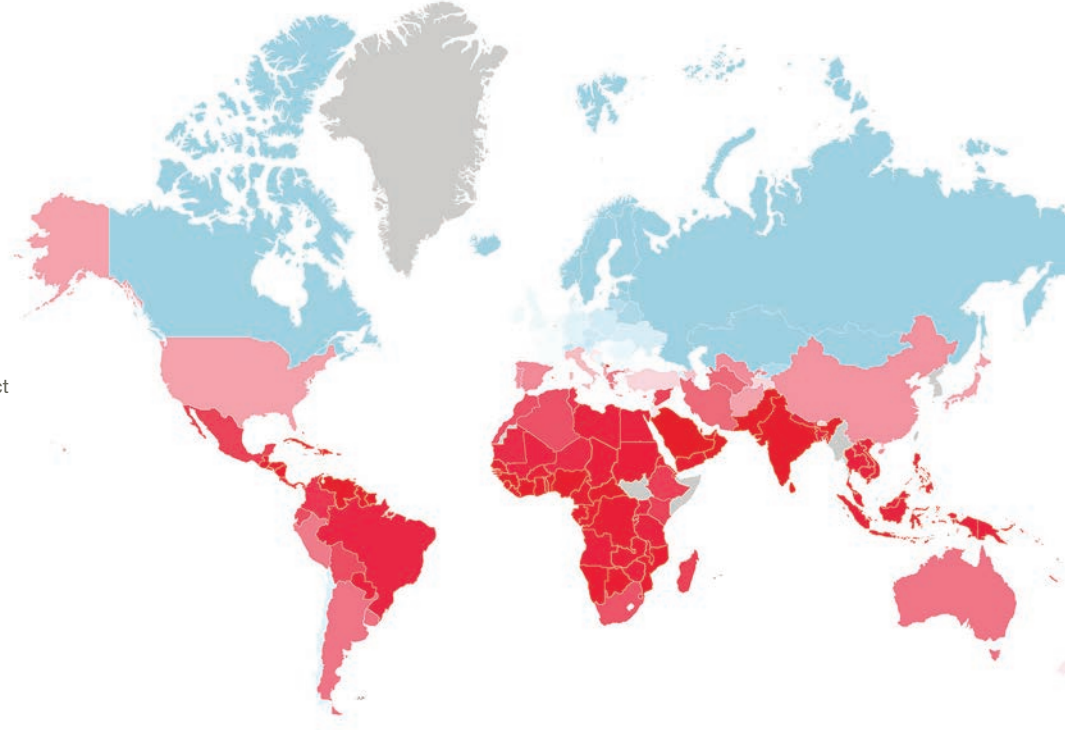
Not only is there evidence that climate is connected to conflict, says his coauthor Marshall Burke, a Stanford professor, but the effects can be substantial. He says, "In sub-Saharan Africa, when temperatures are a degree warmer, we see 20 to 30 percent increase in civil conflict. That's a huge number."

One explanation might lie in the way climate changes affect agriculture. Take the war in Syria, for example. Beginning in the winter of 2006-2007, the Fertile Crescent, which runs across northern Syria and provides the country with much of its food, experienced a three-year drought that was the most severe on record. It prompted as many as 1.5 million people to migrate to the country's urban centers. These formerly rural people joined more than a million refugees from Iraq's war of the mid-2000s, who were already living in the areas surrounding Syria's cities. There, growing crime, inadequate infrastructure, overcrowding, and a lack of response from the government all contributed to unrest. Widespread uprisings in these urban outposts quickly spun into today's civil war, which began in early 2011.

Climate change made the drought far more severe, and the subsequent widespread crop failure and resulting mass migration contributed to the conflict, says

The Unequal Effects of Climate Change in 2100

If global warming is largely unchecked, it will severely damage the economic productivity of many countries, particularly those in Africa, Asia, and South America. Colder countries, such as Russia and Canada, could benefit.



BURKE, HSIANG, MIGUEL

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Colin Kelley, a climate scientist at the University of California, Santa Barbara, who has specialized in the Mediterranean region. In a recent paper, Kelley and his coauthors document how rising levels of greenhouse gases disrupted the normal patterns of wind that bring moisture from the Mediterranean during the winter rainy season. It's part of a long-term drying effect in the region and consistent with predictions from climate-change models, he says. In general, he adds, subtropical regions around the world, such as the Fertile Crescent, are expected to become more arid.

Some political scientists aren't convinced that such climate effects trigger wars. "There is more that we don't know than what we do know, but we do know there is no general and direct relationship between climate variability and large-scale organized wars," says Halvard Buhaug of the Peace Research Institute Oslo in Norway. Still, Buhaug does say it "makes sense" that climate change might exacerbate the main causes of civil war, which he says include systemic inequality, severe poverty, and poor governance. "If climate change affects groups in society differently or presents challenges too severe or too great for political systems to respond," he says, "then of course climate change might contribute to more instability in the future."

The relative importance of the drought in causing the Syrian war is very difficult to untangle from the other factors, Kelley acknowledges. But, he says, determining the specific role of climate is not merely an academic question, especially in regions as volatile as the Middle East. "Who's next?" he asks. "What countries will climate change push over the edge?"

Costs

The research on the links between climate change and conflict is part of a larger effort to better understand the economic and social impact that rising temperatures will have on people in various parts of the world. The effort is designed to improve on previous analyses that often involved crude back-of-the-envelope calculations of impacts averaged over large areas. "Until a few years ago," says Berkeley's Hsiang, "we really had no idea what was coming down the road."

In an attempt to make economic forecasts more rigorous, Hsiang and his colleagues, who include climate scientists and social scientists, have looked at how temperature has affected labor productivity and agriculture in different countries over the years. In a paper published this fall in *Nature*, the group examined how yearly changes in temperature affected economic output in 160 countries between 1960 and 2010. Then they combined the data with climate-change models developed by dozens of teams around the world that predict how temperatures will change with global warming. The result is a projection of economic growth throughout the next century.

The findings are disturbing. The scientists expect that if climate change continues largely unabated, global economic output will drop 23 percent by century's end, a much higher cost than previously predicted. The researchers found that economic output universally declines as average yearly temperatures rise above 13 °C; labor performance, productivity, and agriculture output begin dropping as temperatures increase. Surprisingly, the drop after 13 °C is seen in both rich and poor countries, regardless of whether the economy was dependent on agriculture or nonagricultural industrial sectors.

But perhaps the most shocking finding is just how uneven the impacts will be. Since poorer countries already tend to be hotter, they will feel the brunt of the damage. While the economies of China, India, and much of South America suffer, those of Western Europe, Russia, and Canada could actually benefit. "It would be the largest redistribution of wealth from the poor to the wealthy in history," Hsiang says. "It's incredibly regressive."

How the world's politicians and populations respond to this growing wealth inequality could be the most critical uncertainty we face. And Snyder reminds us how badly things can go if politicians and rulers prey on the fears and prejudices of their people.

One of the most powerful lessons from Hitler's regime has to do with, as Snyder puts it, "conflating science with politics." Rightly, he points an accusing finger at climate-change deniers motivated by political ideology. Likewise, he might have cited those on the other end of the political spectrum who turn their backs on technology and science, rejecting options such as nuclear power and genetic advances in agriculture that could help lessen the impact of climate change. Rather, he argues, policy decisions must be informed by objective scientific results.

Despite all the uncertainties about the future of climate change, the science is clear on a few basic points. We must move as quickly as possible to transform our energy infrastructure so that we can reduce carbon emissions and, by around midcentury, essentially stop such pollution altogether. But the science is also beginning to tell us that even radical steps to curb emissions may not be enough. The damage from climate change is already beginning to hurt people in many parts of the world and will escalate even if emissions begin to drop soon. It's time we figured out how to adapt. And that's where the recent research clarifying the social and economic costs could help. "The climate *is* going to change," says Hsiang. "We need to figure out how to minimize the losses."

David Rotman is editor of MIT Technology Review.

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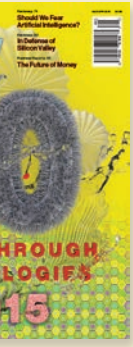
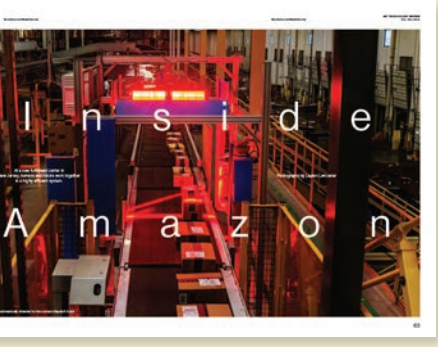
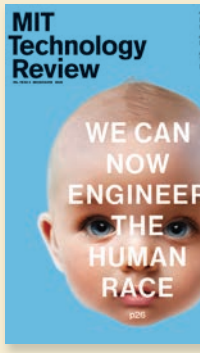
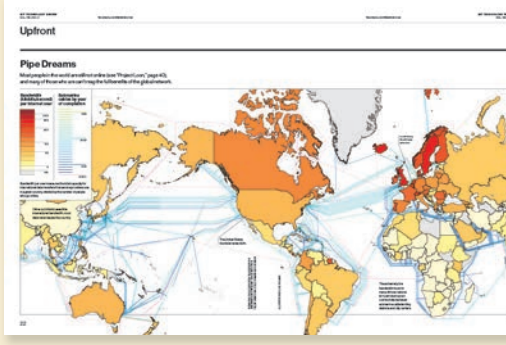








The End of Internet Advertising as We've Known It

Millions of people are refusing to let intrusive, distracting, or irrelevant ads load on their devices. It's an opportunity for consumers to demand a more mutually beneficial relationship with online advertisers.

By Doc Searls

My sister, a retired U.S. Navy commander, has a perfect military expression for what she does with her Sunday newspaper when it arrives: she "field-strips" it. Out go advertising inserts and other unwanted sections, sometimes before the paper even gets inside her house. Same goes for junk mail. The wheat gets in the door; the chaff goes in the bin.

Online, we have ad blockers to field-strip websites automatically. And before long, most people probably will deploy them. In its Digital News Report 2015, the

GARY TAXALI

Reuters Institute for the Study of Journalism reported that 47 percent of people surveyed in the United States "regularly use ad-blocking software." According to PageFair and Adobe's 2015 Ad Blocking Report, the worldwide number of people who stop ads from reaching their computers exceeded 200 million last May (see "The Fast Rise of Ad Blockers," page 20).

As boycotts go, ad blocking must be the largest in history. And it will only get bigger now that Apple supports "content blocking" on its devices, opening up even more ways for individuals to control what does and doesn't get inside their virtual doors.

Ad blocking isn't a new thing. Henrik Aasted Sørensen wrote the original Adblock extension—a program anyone can download and run in a Web browser—in 2002. Yet the technology didn't take off until a decade later. What changed?

I think the biggest reason people are rejecting ads can be summed up in one word: tracking. Over the past decade, companies have increasingly used technology lurking beneath the surface of online ads to capture as much data about us as possible. Advertisers don't have to build this capability for themselves: they rely on ad delivery networks that claim they can show relevant ads to people no matter which website they're visiting. Shoshana Zuboff of Harvard Business School calls this rampant practice "surveillance capitalism."

Perhaps the most bizarre illustration of this phenomenon at work is a poster published in 2013 by IBM and the Aber-

deen Group research firm, headlined "The Big Datastillery." It shows "clickstreams" (the details of our every mouse movement or finger swipe online), social media, and other sources of data flowing through pipes into a big hopper. At the bottom, "customer interaction optimization" and "marketing optimization" spigots pour distilled goop into empty beakers moving down a conveyor belt. Each empty beaker represents the "right person" getting the "right offer" through the "right channel" at the "right time." Near the end of the belt, each beaker farts gases upward into a funnel collecting "campaign metrics" to feed back into the top of the hopper.

If you look at the numbers in callouts by the plumbing, you'll see that even what IBM and Aberdeen call "Best-in-Class" marketing, generated by surveillance, gets less than 10 percent of customers to respond. Why? We're rarely actually looking to buy anything. We're just going about our lives, doing whatever we do, which isn't marketers' business unless we say it is.

Digital News Report 2015
Reuters Institute for the Study of Journalism, University of Oxford
June 16, 2015

The 2015 Ad Blocking Report
PageFair and Adobe Systems
August 10, 2015

It's telling that when the authors of the PageFair-Adobe report asked 400 Americans why they started using an ad blocker, the primary reason they gave was to avoid "misuse of personal information." Twelve months ago, the research firm Ipsos surveyed people on behalf of the marketing services company TRUSTe and found that concern about online privacy was rising. The top cause for worry: "Companies collecting and sharing my personal information with other companies." People feared that more than government surveillance. So it's no wonder that ad blocking hockey-sticked in popularity after it became clear that other mechanisms for protecting personal privacy—such as "Do Not Track" (a function you can activate in your Web browser to request that sites not compile information on you)—were mostly ignored by the online advertising business. When Do Not Track proved toothless, millions of people got their own fangs.

That means we've gained bargaining power with advertisers and publishers. What should we bargain for?

The first and easiest answer is: advertising that's not based on tracking our every step. In other words, the old-fashioned Madison Avenue kind that is still what we get in the offline world.

Even if we don't like ads fattening our magazines and interrupting our TV shows, we at least know the economic role

they play and appreciate the best ones, which can be every bit as good as the content they sponsor. These ads send strong signals about brands, and yet they respect our privacy, don't plant tracking beacons on us, and don't lure us away from what we're doing. The attractive ads that populate *Vogue* and other high-quality offline media are advertising's wheat. The kind that drive millions of us to use ad blockers are advertising's chaff.

There are already some means for threshing the two apart online. The most popular ad blocker, Adblock Plus, by default lets through what it calls "acceptable" ads—though the company also, controversially, makes money by charging some companies whose ads it accepts. Many tools to observe and block tracking by ads—Bouncer, Disconnect, DoNotTrackMe, Ghostery, Lightbeam, NoScript, PrivacyFix, Privowny, and Web Pal, to name a few—also have the effect of blocking some of advertising's chaff.

When researchers asked people why they started using an ad blocker, the primary reason they gave was to avoid "misuse of personal information."

More important, any of these tools can evolve to actually help match consumer demand with advertisers' supply in ways that don't rely on surveillance-fed guesswork. I am talking about a technology that I call "intentcasting." This is where you and I do the advertising, notifying a marketplace that we need some product or service. For example: "I need a sump pump for a flooded basement, ASAP," or "I need the sensor on my Nikon camera cleaned without sending it off somewhere."

These requests (called "qualified leads" on the receiving end) can also be issued anonymously. ProjectVRM, which I run at Harvard's Berkman Center, lists nearly two dozen intentcasting startups and other development projects.

Creative ways of using existing ad delivery networks to facilitate specific customer requests are being developed. Browser makers could also provide intentcasting platforms. Mozilla, maker of the Firefox browser, brought me in as a consultant to (among other things) help make that happen. And since Mozilla open-sources its code, other browser makers are free to join in as well.

Think about how much more sensible it would be to let customers roam free and undisturbed with tools for giving truly valuable information to the supply side of the marketplace. Then think about how much money could be saved by shutting down the marketing machinery aimed at manipulating people who have already marked the output of that machinery down to the value of spam. Finally, think about how much more pleasant the online world would be.

Until that future arrives, we should permit advertising we actually can tolerate. This puts a burden on advertisers to make clear that the wheat it produces is good for us. The way to do that is by giving us the best of what advertising has always been: a creative art form. Why not use the Internet as a medium for that, rather than just for fracking personal data and using it to spam people with annoying guesses that mostly don't work?

Otherwise, marketers are just inviting you to field-strip them.

Doc Searls is senior editor of Linux Journal *and a fellow of the Center for Information Technology and Society at the University of California, Santa Barbara. He is also an alumnus fellow of Harvard's Berkman Center for Internet and Society.*

R. KIKUO JOHNSON

Are Young Athletes Risking Brain Damage?

Sports leagues should do more to protect children from the long-term problems that stem from hits to the head.

By Amanda Schaffer

In the new movie *Concussion*, Will Smith plays a neuropathologist who performed a game-changing autopsy on former Pittsburgh Steelers center Mike Webster in 2002. After a career in which Webster earned four Super Bowl rings and a spot in the Pro Football Hall of Fame, he suffered from memory loss, depression, and dementia, was homeless at times, and died at age 50. (The movie is based on a *GQ* article that describes Webster's psychiatric symptoms, including "pissing in his oven and squirting Super Glue on his rotting teeth.") When the neuropathologist, Bennet Omalu, analyzed Webster's brain tissue, he discovered clumps of tau proteins, generally associated with neurodegeneration. In 2005, he published a paper arguing that Webster had suffered from what he recognized as chronic traumatic encephalopathy, or CTE, brought on by more than two decades of brain battering on the field.

As Omalu and others studied the brains of dozens of former players who had died, they continued to discover signs of CTE. Not surprisingly, the National Football League fought to discredit the work, possibly hoping to avoid expensive disability payments to ex-players. "You're going to war with a corporation that owns a day of the week," an associate warns Omalu in *Concussion*. Yet despite the NFL's obstructionism, the connection between repetitive head injury and neurodegenerative disease has only grown stronger with time. While many athletes who suffer concussions do not go on to develop CTE, every time it crops up in an autopsy it's in someone who "had a history of repetitive hits to the head," says Robert Stern, director of the clinical core of the Alzheimer's Disease Center at the Boston University School of Medicine.

The issue now extends far beyond the NFL to children who play football, soccer, hockey, and other sports, especially because new research is revealing

the pervasiveness of head injury in young athletes. Neuroscientists are finding that concussion can affect brain function in subtle ways, and that kids may have a special vulnerability. It's possible that better helmets and other equipment could play some role in reducing the risk, but they are unlikely to solve the problem. It's time to change the rules of the games.

Concussion
Sony Pictures, 2015

Long-term consequences

In 2013, a report from the Institute of Medicine called for greater attention to concussions across the age spectrum, but especially in younger kids. In response, epidemiologists from the Datalys Center for Sports Injury Research and Prevention in Indiana analyzed information collected by athletic trainers in 2012 and 2013. They found that roughly one in 20 college football players sustained at least one concussion in the course of a season. Among high school students, that number was one in 14. And among youth players, it was one in 30, though lead researcher Tom Dompier told me he suspects that last number is an underestimate. Concussion occurs when the brain slams against the inside of the skull, but 90 percent of the time it does not cause loss of consciousness or other very obvious effects. So especially among five- to seven-year-olds, it's possible that they "just didn't know how to articulate" their symptoms, Dompier says.

Other researchers are trying to better identify concussion symptoms that can show up long after a game. These can include behavioral changes like temper tantrums and irritability, according to Kristy Arbogast, co–scientific director of the Center for Injury Research Prevention at the Children's Hospital of Philadelphia. In some children, concussion can cause subtle disruptions to ocular motor coördination that were not routinely evaluated in the past. These can lead to headaches, dizziness, and nausea when kids return to school and try to focus on the blackboard. "We're finally getting some clarity on what concussion looks like at different ages and in different children," she says. That, she adds, will allow physicians to diagnose and treat more cases.

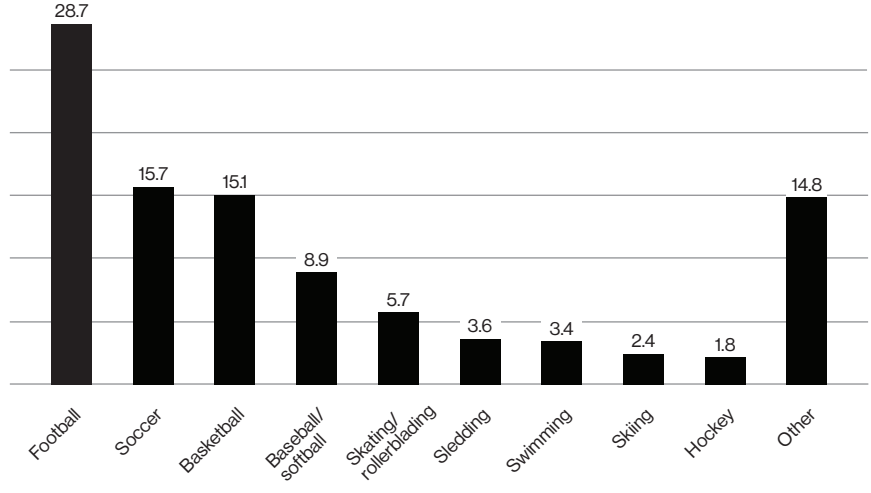
At the same time, scientists are pinpointing how head injury affects young brains. To date, no one has performed a critical experiment in which children who play contact sports are followed for decades. But several lines of evidence suggest that concussions and even lesser head trauma can have long-term consequences for them, challenging the conventional wisdom that the young brain's plasticity makes it more resilient. "Plasticity doesn't seem to work that way," says Stern. Instead, he argues that during certain windows of development, children's brains may actually be more vulnerable to lasting damage than adults'.

Stern and his colleagues have categorized a group of retired NFL players according to whether they began playing before or after the age of 12. Controlling for the total number of years in football, the researchers found that those who started earlier fared worse on tests of cognitive flexibility and executive function. An advanced version of magnetic resonance imaging also showed that these players had more disruptions to a bundle of nerve fibers, or axons, called the corpus callosum. Between the ages of eight and 12, the brain undergoes a period of intense axonal growth and myelination (in which an insulating layer accumulates around the nerve cells), facilitating communication. Stern speculates that the players who started earlier may have sustained axonal injuries that prevented their brains from developing fully during this critical window, leading to long-term impairment.

Last year, researchers at Purdue University compared the neurocognitive function of high school football players before and after a single season. Strikingly, even athletes who had not suffered a diagnosable concussion performed worse on tests of visual memory after months of football. The study was small, and it's unclear

Rough Play

From 2002 through 2011, 3,878 patients came to the emergency room of the Cincinnati Children's Hospital Medical Center with a sports-related brain injury. The percentage of cases by sport:



PEDIATRICS, 2013

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whether its findings can be generalized. But it's reasonable to be concerned about brain changes brought on by head impact, however subtle. "We do everything to make sure our kids have the best possible chance at success in life," says Stern. "And yet we drop them off at a field and say, 'Go hit your head over and over again.' It's incongruous."

That's why sports leagues must do much more to reduce the frequency and intensity of head impacts. In soccer, young children simply should not be heading the ball. Last year, a group of parents filed a class action suit against FIFA, U.S. Soccer, and the American Youth Soccer Organization to force restrictions on this practice. In November, the suit was settled with the U.S. Soccer Federation, which announced a ban on heading for children 10 and younger and limitations on heading during practice for kids between the ages of 11 and 13. (For technical reasons, the suit against FIFA was not allowed to proceed.) This is actually just a small step; if it's true that children experience a critical window of brain development before the age of 12, they should not be expected to head the ball at age 11. In other sports, too, more could be done: in baseball, leagues could outlaw head-first slides into bases. The leaders of USA Hockey have already forbidden body-checking, in which a player is slammed into the wall around the ice, for kids under 13. But that will have limited effect unless the rules are strictly enforced.

In one study, high school football players got worse at memory tests even if they had not been diagnosed with a concussion.

Much of the head hitting in football occurs during practices, as research by Dompier and others shows. That can be minimized through coach education and prudent changes. For instance, old-time coaches often assigned young players to activities like the Oklahoma drill, in which players line up a few feet apart and run at each other. "Once you outlaw silly drills like that and limit how many hours the kids can do full contact, you can actually make practices pretty safe," he says. In 2012, the Pop Warner youth football organization instituted new restrictions on blocking and tackling drills. But even contact-free practices leave kids vulnerable to concussions in games, which is why bigger changes should follow. Youth leagues should switch to flag football and ban tackling for kids under 14. And high school leagues should end kickoff and punt returns, in which players charge full speed at each other from opposite directions. (Even the NFL has changed the yard line for kickoffs to reduce the number of returns.)

Further research is still required to understand how common concussions really are in kids and how their brain structure and cognitive function may be affected years after playing contact sports. Leagues might mandate helmet sensors to detect the frequency and force of hits, though the severity of impacts that cause concussions can vary from person to person. What ultimately needs to be developed is a quick blood test, such as a screen for the proteins that appear in elevated amounts after a brain injury.

In the meantime, as the NFL's history shows, we shouldn't ignore potentially devastating evidence or assume we know how serious repeated head contact is. It's true that we can't easily generalize from adults to kids. But if ever there were cause for extreme caution, children's brains are it.

Contributing editor Amanda Schaffer wrote about the "great man" myth of technology development in July/August 2015.

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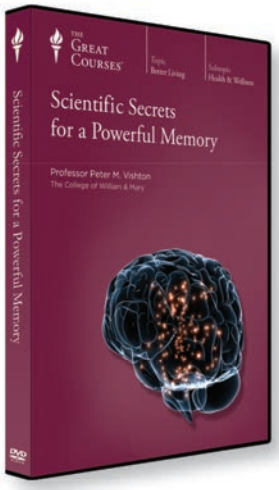

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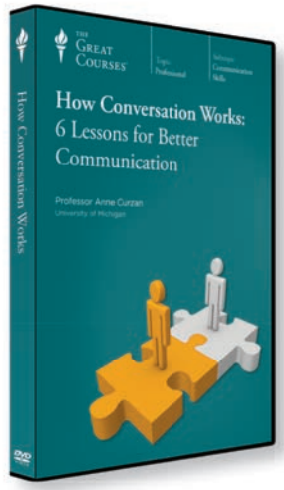

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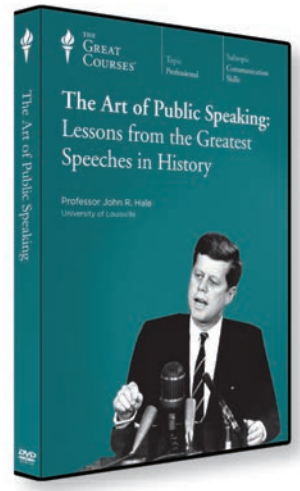

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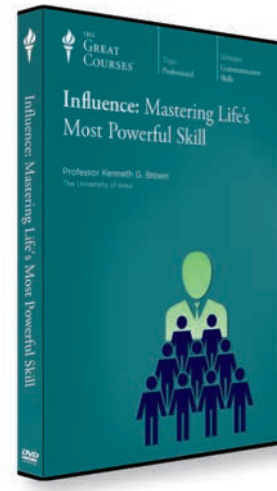

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Demo


Peidong Yang

The Ideal Fuel

A nanomaterials chemist has figured out a good way to mimic leaves and turn water and carbon dioxide into things we need.

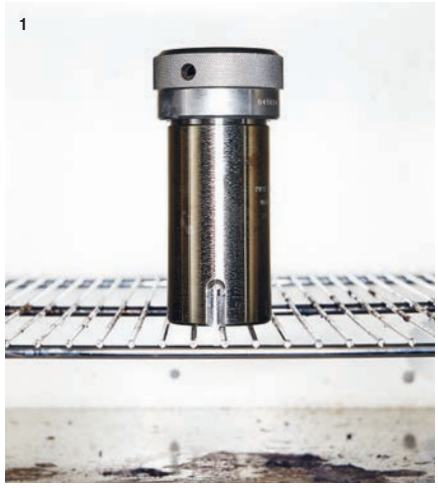
By Katherine Bourzac
Photographs by RC Rivera

On a sunny day on the campus of the University of California, Berkeley, the peaceful rustling of eucalyptus trees belies the furious chemical activity happening inside every single leaf. Through photosynthesis, leaves use the energy in sunlight to turn water and carbon dioxide into substances that plants need, emitting only oxygen in the process. In a nearby lab, chemist Peidong Yang is building an artificial system that does the same, using arrays of nanowires coupled with engineered bacteria. If something like this is ever scaled up, it would churn out a better version of the fuels we use today—one that does not add to the total amount of carbon dioxide in the air.

Photosynthesis has been very difficult to imitate in the lab. In the 1970s, researchers at the University of Tokyo showed for the first time that a solar-powered device could do what plants do in the first step of photosynthesis: split water into hydrogen and oxygen. After an initial burst of activity,

1 This small reactor filled with chemical precursors and water is heated in an oven to grow titanium dioxide nanowires.

2 Silicon nanowires are grown from gaseous precursors flowing through this reactor.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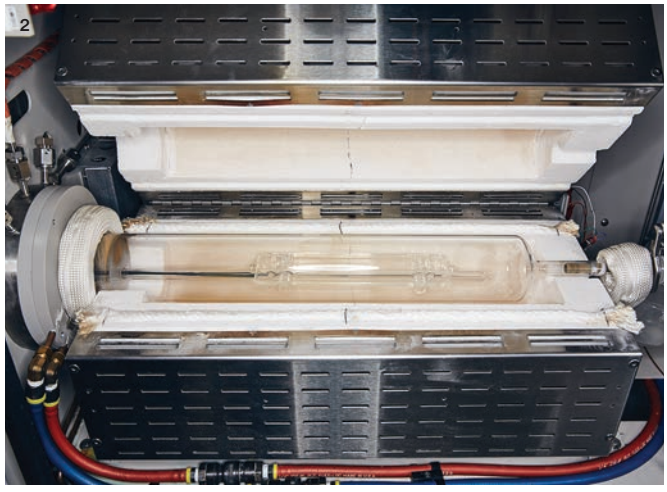
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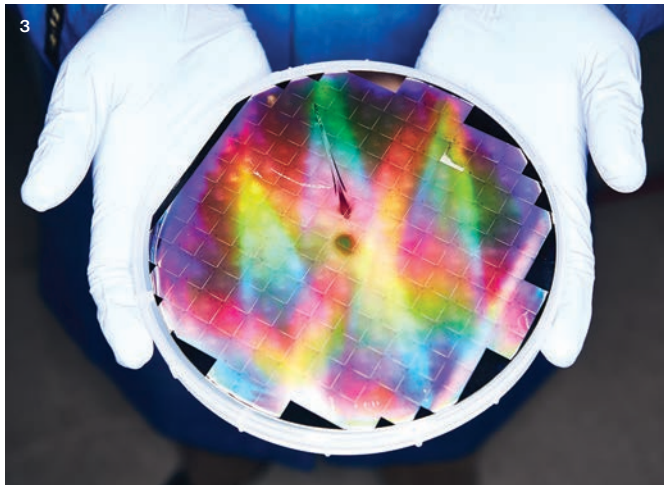
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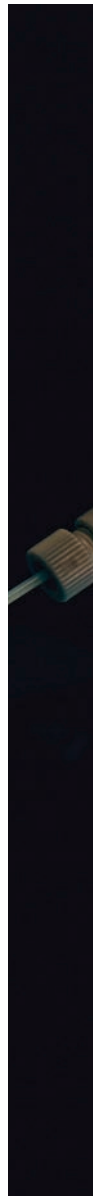

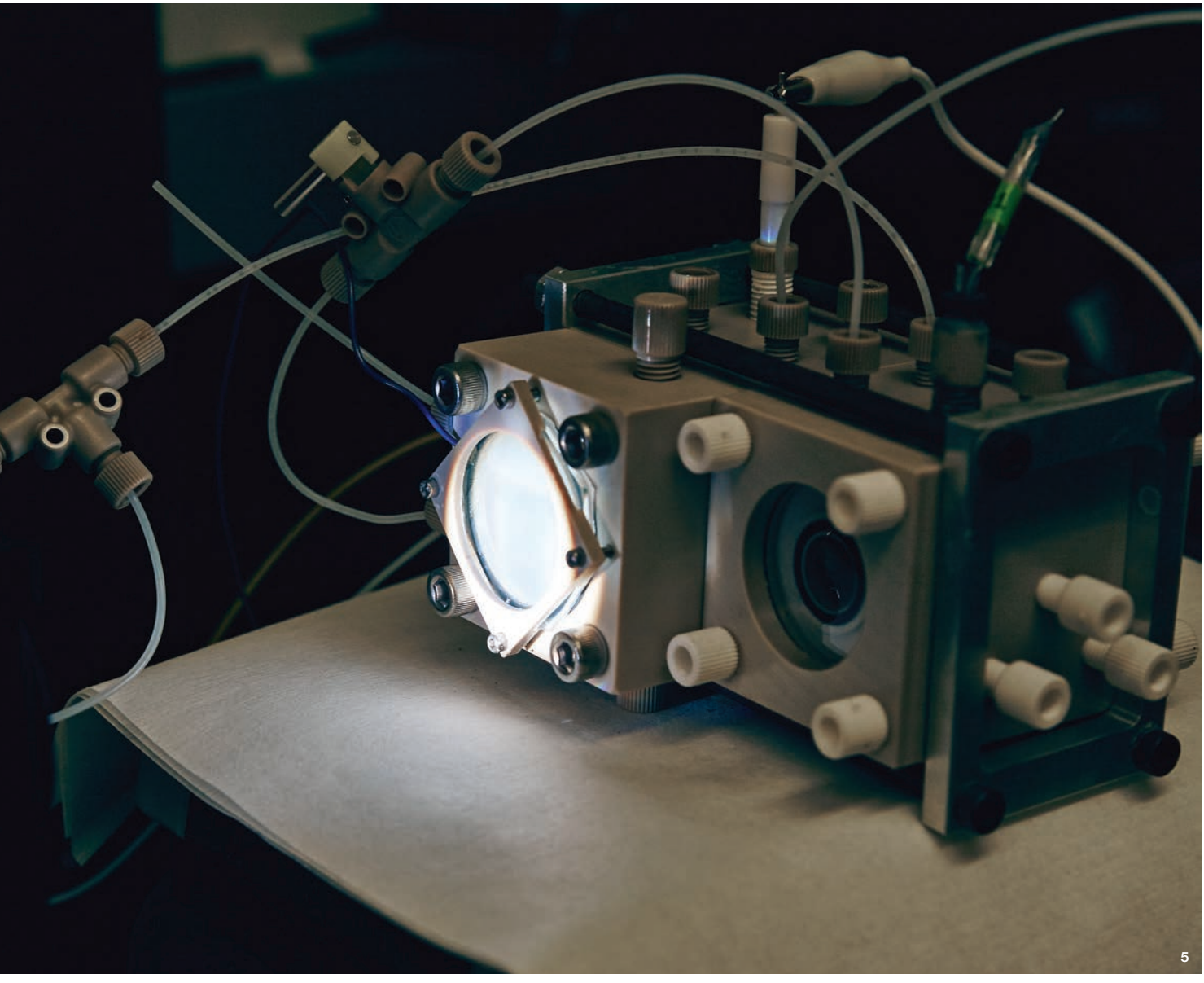

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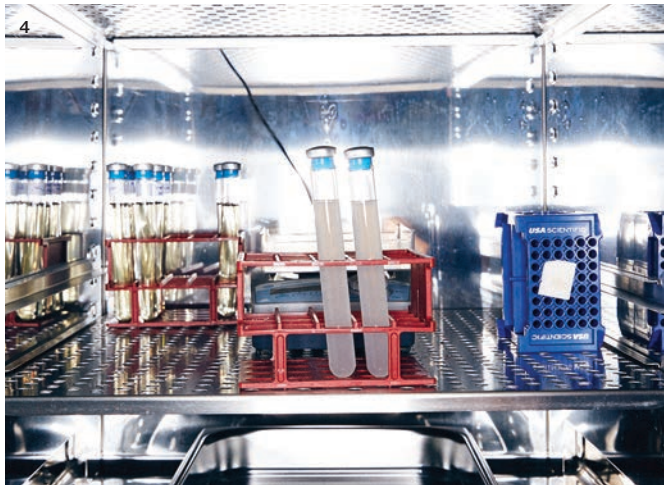

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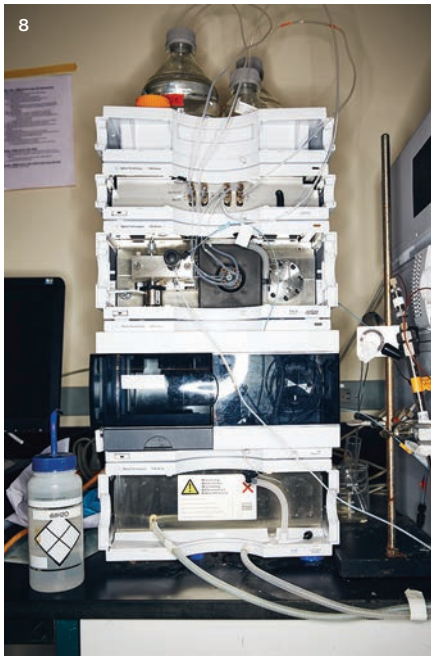
3 Silicon nanowires can also be grown on larger surfaces such as this wafer. It gets cut into pieces that serve as electrodes inside the device.

4 Bacteria in this incubator will be seeded on an electrode to act as living catalysts.

5 Inside this device, light powers a reaction in which water and carbon dioxide are converted to fuel. Tubing allows the reaction's side product—pure oxygen—to escape.



6 and 7 Some bacteria in the system produce methane, which can be used directly as a fuel; others make acetate, which is fed to other genetically engineered bacteria to make fuels and plastics. Here, engineered *E. coli* feed on acetate.

8 Analytical tools including mass spectrometers are used to verify that the bacteria made the desired chemical. So far, the system is as efficient as natural photosynthesis.

the field stalled. But it has been reborn in several labs thanks to a renewed focus on the energy problem and climate change—and because of the emergence of new technologies.

Yang's lab is improving on a basic design that was developed in the 1970s at the National Renewable Energy Laboratory. It has two light-sensitive electrodes coated with a catalyst—Yang is using nickel, which is inexpensive—that together split water into oxygen and hydrogen. In the original setup, the electrodes were flat, but Yang instead uses arrays of nanowires made from silicon and other semiconductors. Because the nanowires have 100 times the surface area of flat electrodes that could fit into the same space, they can hold more of the catalyst, greatly boosting the efficiency of the reaction.

However, splitting water is the easy half of photosynthesis. Plants go further, using the hydrogen from water in reactions that turn carbon from the air into complex molecules. Yang wants to do this too. After all, our planes and cars don't run on hydrogen; they need gasoline and other chemically complex fuels.

To catalyze that part of the process, Yang relies on another technology that wasn't around in the '70s. He and colleagues have shown that genetically engineered bacteria nestled amid the nanowires function as "living catalysts." They take up the hydrogen split from the water and combine it with carbon dioxide to make methane and other hydrocarbons that are needed for fuels or plastics. The bugs do this with natural enzymes that carry out a series of reactions chemists have not yet been able to master with synthetic catalysts.

Yang's system currently matches the efficiency of photosynthesis, storing under 1 percent of the energy captured from sunlight in the form of chemical bonds. That's not bad for a proof-of-concept demonstration, but making it more efficient and thus cost-effective will be essential.

Yang hopes to eventually switch to synthetic catalysts instead of bacteria, which are tricky to keep alive. But fully eliminating the bugs might not be necessary, given the urgent need for clean fuels. "If it has to be a hybrid approach, that's okay," he says.

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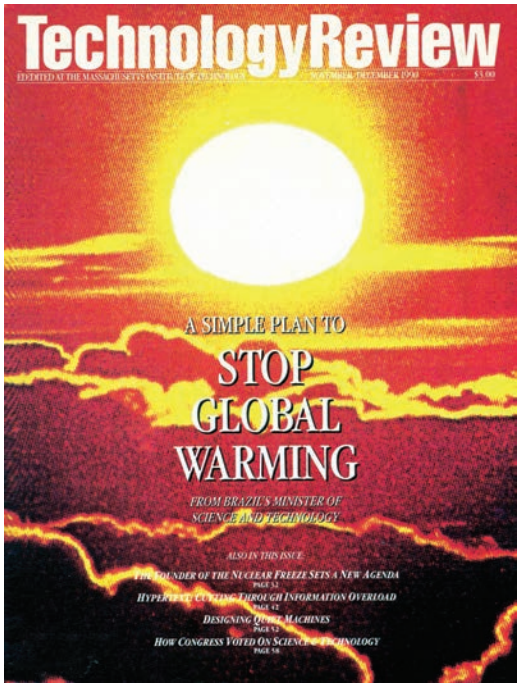

A Conservative Proposition for Global Warming

In 1990, a Brazilian politician proposed what he presumed would be a simple way to kick our fossil-fuel habit.

"The specter of global warming unites humanity in a common task. Every time anyone in the world lights a wood stove, or starts a car, or burns an acre of forest, the atmosphere receives another dose of carbon dioxide and other greenhouse gases that threaten catastrophe in decades or centuries to come.

To stabilize atmospheric concentrations of greenhouse gases at today's levels, the EPA recently estimated that it would be necessary to cut emissions of CO_2 by 50 percent. Unfortunately, such cuts would probably be impractical, because they would severely constrain economic development. A more modest target emerged from the Toronto Conference on Climate Change in 1988. There, the world's industrialized nations agreed on a goal of cutting emissions 20 percent by the year 2005. This would not stabilize levels of greenhouse gases but would at least slow their accumulation.

Since this is a global problem, it makes sense to exact the money needed from the international community. A levy of just $1 per barrel of oil-equivalent, or $6 per ton of coal-equivalent, would generate an income of $50 billion per year—more than enough to pay for the necessary measures.

The purpose of the carbon tax would not be primarily to discourage energy consumption, any more than a highway toll is intended to discourage automobile travel. Rather, the tax would be a fair way to raise the money needed to fund a transition into an ecologically more benign economy.

Admittedly, a carbon tax may not be politically feasible in many countries right now. But attitudes are rapidly changing as people absorb the implications of inaction.

Given the high stakes, an internationally agreed-upon tax is not a very radical step. Coöperation among nations will be based not purely on goodwill but also on enlightened self-interest. The sums of money needed to stabilize the atmosphere are not really that large: $50 billion represents 0.4 percent of the gross domestic product of the industrialized world. Spending such a sum to avoid environmental catastrophe seems a prudent—and, in the most basic sense, conservative—proposition."

Excerpted from "How to Stop Global Warming," by José Goldemberg, Brazil's secretary of state for science and technology, in the November 1990 issue of Technology Review.

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